Eastern Bering Sea
Walleye Pollock Stock Assessment

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Summary

The primary focus of this chapter is on the eastern Bering Sea region. The Bogoslof Island area analysis is presented in separate section below. A new age-structured Aleutian Islands assessment for pollock is presented in separate section.

Changes in the input data
The 2004 NMFS summer bottom-trawl (BTS) and echo-integration trawl (EIT) survey estimates were available for analysis in this assessment. The biomass estimate from the BTS was 3.75 million tons, a substantial drop from the value of 8.14 million tons estimated in 2003 but similar to the model estimate for the BTS in 2003 (4.18 million tons). The 2004 BTS and EIT survey estimates included population numbers at age (using an age-length key derived from the 2004 BTS data). The biomass estimate from this survey was 3.31 million tons, down from 3.6 million tons estimated in 2002 but close to the average estimated by this survey since 1982 (3.36 million tons).

The NMFS observer samples of pollock age and size composition were evaluated for the 2003 fishery and these data were included in the analyses. The estimates of average weight-at-age from the fishery were also revised. The total pollock catch estimate for 2003 was estimated using the NMFS Alaska Region data. The 2004 catch was assumed to equal the TAC (1,492,000 t).

Changes in the assessment model
No major changes to the assessment model were made this year. As in past years, an array of model alternatives was evaluated for contrast. New alternatives presented this year include a re-evaluation of the ageing-error matrix (Model 2) and fitting fishery catch-at-age data (Model 3).

Changes in the assessment results
The 2005 maximum ABC alternatives based on the $F_{40\%}$ and F_{msy} are 1,897 and 1,962 thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value). The 2005 overfishing level (OFL) alternatives for the reference model are 2,325 and 2,104 thousand tons corresponding to $F_{35\%}$ and F_{msy} (arithmetic mean). Stock levels for EBS pollock appear to be lower overall than estimated last year and the projected 2005 biomass is the lowest estimated since 1992. The 2000 year class appears to be above average and the main age group available to the fishery. Subsequent year classes are currently estimated to be below average and will result in further short-term declines in abundance. Projections (based on Tier 3 harvest levels) indicate the ABC could be below 1.1 million t by 2007.

For the Bogoslof region, the maximum permissible ABC and OFL is based on Tier 5. This results in **29,700 t** and **39,600 t** for ABC and OFL, respectively. The SSC have recommended that the Bogoslof ABC be reduced relative to the target stock size (2 million tons). This gives a 2005 ABC of **2,570 t** for the Bogoslof Island region. Note that no survey was conducted in 2004 and that the next survey of this region is planned for winter of 2005. Abundance patterns of the 1992 cohort in the Bogoslof region show

a consistently high level of attrition while this same cohort showed a much lower than expected level of decline in the EBS from BTS data. While the magnitude of the abundances between these areas fails to explain these patterns (e.g., by movement of Bogoslof spawning pollock onto the EBS shelf in the summer), it does suggest that this cohort responded differently between these areas.

Response to SSC comments
The SSC requested further analysis of ageing errors be included. Model 2 (presented below) includes ageing-errors as an alternative. Additionally, Model 3 (described below) provides an alternative where fishery catch-at-age data are allowed to fit precisely (as in a VPA-model) for contrast.

Introduction

Stock structure

In the U.S. portion of the Bering Sea three stocks of pollock are identified for management purposes. These are: eastern Bering Sea which consists of pollock occurring on the eastern Bering Sea shelf from Unimak Pass and to the U.S.-Russia Convention line; the Aleutian Islands Region encompassing the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and the Central Bering Sea—Bogoslof Island pollock. These three management stocks undoubtedly have some degree of exchange. The Bogoslof stock is a group that forms a distinct spawning aggregation that has some connection with the deep water region of the Aleutian Basin. In the Russian EEZ, pollock are considered to form two stocks, a western Bering Sea stock centered in the Gulf of Olyutorski, and a northern stock located along the Navarin shelf from 171°E to the U.S.- Russia Convention line. The northern stock is believed to be a mixture of eastern and western Bering Sea pollock with the former predominant. Bailey et al. (1999) present a thorough review of population structure of pollock throughout the north Pacific region. Recent genetic studies using mitochondrial DNA methods have found the largest differences to be between pollock from the east and western sides of the north Pacific. Other genetic studies are underway and hold promise for resolving stock structure issues (e.g., Canino and Bentzen, 2004; and O’Reilly et al., 2004).

Catch history and fishery data

From 1954 to 1963, pollock were harvested at low levels in the Eastern Bering Sea and directed foreign fisheries began in 1964. Catches increased rapidly during the late 1960s and reached a peak in 1970-75 when catches ranged from 1.3 to 1.9 million t annually (Fig. 1.1). Following a peak catch of 1.9 million t in 1972, catches were reduced through bilateral agreements with Japan and the USSR.

Since the advent of the U.S. EEZ in 1977 the annual average eastern Bering Sea pollock catch has been 1.2 million t and has ranged from 0.9 million t in 1987 to nearly 1.5 million t (including the Bogoslof Islands area catch; Fig. 1.1). Stock biomass has ranged from a low of 4 million t to highs of 12 million t. United States vessels began fishing for pollock in 1980 and by 1987 they were able to take 99% of the quota. Since 1988, only U.S. vessels have been operating in this fishery. By 1991, the current NMFS observer program for north Pacific groundfish-fisheries was in place.

Foreign vessels began fishing in the mid-1980s in the international zone of the Bering Sea (commonly referred to as the “Donut Hole”). The Donut Hole is entirely contained in the deep water of the Aleutian Basin and is distinct from the customary areas of pollock fisheries, namely the continental shelves and slopes. Japanese scientists began reporting the presence of large quantities of pollock in the Aleutian Basin in the mid-to-late 1970's, but large scale fisheries did not occur until the mid-1980's. In 1984, the Donut Hole catch was only 181 thousand t (Fig. 1.1, Table 1.1). The catch grew rapidly and by 1987 the high seas catch exceeded the pollock catch within the U.S. Bering Sea EEZ. The extra-EEZ catch peaked in 1989 at 1.45 million t and has declined sharply since then. By 1991 the donut hole catch was 80% less than the peak catch, and data for 1992 and 1993 indicate very low catches (Table 1.1). A fishing moratorium was enacted in 1993 and only trace amounts of pollock have been harvested from the Aleutian Basin by resource assessment fisheries. During 2002-2004 the EBS region pollock catch has averaged 1.46 million tons while for the period 1982-2001, the average was 1.15 million tons. The effect of this level of fishing continues to be closely monitored by an extensive fishery observer program and extensive survey work.

Fishery characteristics

The pattern of the modern fishery (since the early 1990s) has been focused on a winter, spawning-aggregation fishery (the "A-season) with an opening on January 20th. This first season typically lasts about 4-6 weeks, depending on the catch rates. A second season opening has occurred on September 1st (though 1995 opened on Aug 15th). This has changed considerably since 1998. Currently, the first season generally extends into the middle of March and the summer season begins in mid-late June.

Since the closure of the Bogoslof management district (INPFC area 518) to directed pollock fishing in 1992, the "A-season" (January – March) pollock fishery on the eastern Bering Sea (EBS) shelf has been concentrated primarily north and west of Unimak Island (Ianelli *et al.* 1998). Depending on ice conditions and fish distribution, there has also been effort along the 100 m contour (and deeper) between Unimak Island and the Pribilof Islands. This pattern has varied somewhat during the period 2002 - 2004 (Fig. 1.2). In particular, the 2003 winter fishery was distributed further north than in previous years. This may be due to the warm conditions and anecdotal reports that roe developed earlier than usual. The total catch estimates by sex for the A-season compared to the fishery as a whole indicates that over time, the number of males and females has been fairly equal (Fig. 1.3). The length frequency information from the fishery shows that the size of pollock is generally larger than 40 cm but with some smaller fish caught during years when a strong year class appeared (Fig. 1.4).

After 1992, the "B-season" (typically September – October) fishery has been conducted to a much greater extent west of 170°W than it had been prior to 1992 (Ianelli *et al.* 1998). This shift was due to the implementation of the CVOA (Catcher Vessel Operational Area) in 1992 and also the geographic distribution of pollock by size. The pattern in the past few years shows consistent concentrations of catch around the Unimak Island area and along the 100 m depth contour to the northwest of the Pribilof Islands. (Fig. 1.5). The length frequency information from the fishery reveals a marked progression of the large 1989 year class growing over time and the appearance of the 1992 year class in 1996-97, the 1996 year class in 1998-2001, and subsequently the 2000 year class (Fig. 1.6). The 2003 fishery data shows an unusually high mode of fish at around 40cm that advances to 45cm in 2004 (preliminary data). This is consistent with an indication of a strong 2000 year class (with some possible confounding of the 1999 year class).

Fisheries Management

In response to continuing concerns over the possible impacts groundfish fisheries may have on rebuilding populations of Steller sea lions, NMFS and the NPFMC have made changes to the Atka mackerel (mackerel) and pollock fisheries in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA). These have been designed to reduce the possibility of competitive interactions with Steller sea lions. For the pollock fisheries, comparisons of seasonal fishery catch and pollock biomass distributions (from surveys) by area in the eastern Bering Sea (EBS) led to the conclusion that the pollock fishery had disproportionately high seasonal harvest rates within critical habitat that *could* lead to reduced sea lion prey densities. Consequently, the management measures were designed to redistribute the fishery both temporally and spatially according to pollock biomass distributions. The underlying assumption in this approach was that the independently derived area-wide and annual exploitation rate for pollock would not reduce local prey densities for sea lions. Work continues on evaluating the effectiveness of these measures and the potential for adverse fishery and Steller sea lion (or other marine mammal) interactions. These are presented in the ecosystem considerations section below.

Three types of measures were implemented in the pollock fisheries:

- Pollock fishery exclusion zones around sea lion rookery or haulout sites,
- Phased-in reductions in the seasonal proportions of TAC that can be taken from critical habitat, and
- Additional seasonal TAC releases to disperse the fishery in time.

Prior to the management measures, the pollock fishery occurred in each of the three major fishery management regions of the north Pacific ocean managed by the NPFMC: the Aleutian Islands (1,001,780 km^2 inside the EEZ), the eastern Bering Sea shelf (968,600 km^2), and the Gulf of Alaska (1,156,100 km^2). The marine portion of Steller sea lion critical habitat in Alaska west of 150°W encompasses 386,770 km^2 of ocean surface, or 12% of the fishery management regions.

Prior to 1999, a total of 84,100 km^2, or 22% of critical habitat, was closed to the pollock fishery. Most of this closure consisted of the 10 and 20 nm radius all-trawl fishery exclusion zones around sea lion rookeries (48,920 km^2 or 13% of critical habitat). The remainder was largely management area 518 (35,180 km^2, or 9% of critical habitat) which was closed pursuant to an international agreement to protect spawning stocks of central Bering Sea pollock.

In 1999, an additional 83,080 km^2 (21%) of critical habitat in the Aleutian Islands was closed to pollock fishing along with 43,170 km^2 (11%) around sea lion haulouts in the GOA and eastern Bering Sea. Consequently, a total of 210,350 km^2 (54%) of critical habitat was closed to the pollock fishery. The portion of critical habitat that remained open to the pollock fishery consisted primarily of the area between 10 and 20 nm from rookeries and haulouts in the GOA and parts of the eastern Bering Sea foraging area.

The Bering Sea/Aleutian Islands pollock fishery was also subject to changes in total catch and catch distribution. Disentangling the specific changes in the temporal and spatial dispersion of the EBS pollock fishery resulting from the sea lion management measures from those resulting from implementation of the American Fisheries Act (AFA) is difficult. The AFA reduced the capacity of the catcher/processor fleet and permitted the formation of cooperatives in each industry sector by 2000. Both of these changes would be expected to reduce the rate at which the catcher/processor sector (allocated 36% of the EBS pollock TAC) caught pollock beginning in 1999, and the fleet as a whole in 2000. Because of some of its provisions, the AFA gave the industry the ability to respond efficiently to changes mandated for sea lion conservation that otherwise could have been more disruptive to the industry.

In 2000, further reductions in seasonal pollock catches from BSAI sea lion critical habitat were realized by closing the entire Aleutian Islands region to pollock fishing and by phased-in reductions in the proportions of seasonal TAC that could be caught from the Sea Lion Conservation Area, an area which overlaps considerably with sea lion critical habitat. In 1998, over 22,000 t of pollock were caught in the Aleutian Island regions, with over 17,000 t caught in AI critical habitat. Since 1998 directed fishery removals of pollock have been prohibited.

On the eastern Bering Sea shelf, an estimate (based on observer at-sea data) of the proportion of pollock caught in Steller sea lion critical habitat (SCA) has averaged about 44% annually. During the “A-season,” this figure increases to about 53% (since pollock are more concentrated in this area during this period). The proportion of pollock caught within the SCA has varied considerably, presumably due to temperature regimes and population age structure. Since 2001 the proportions by season have become less variable. The pattern of catch since 1998 is shown below:

Year	Months	Catch outside SCA	Catch Total	Percent of catch inside SCA
1998	Jan-Jun	71	385	82%
	Jul-Dec	248	403	39%
	Jan-Dec	318	788	60%
1999	Jan-Jun	155	339	54%
	Jul-Dec	360	468	23%
	Jan-Dec	515	807	36%
2000	Jan-Jun	241	375	36%
	Jul-Dec	550	572	4%
	Jan-Dec	791	947	16%
2001	Jan-Jun	357	490	27%
	Jul-Dec	367	674	46%
	Jan-Dec	724	1,164	38%
2002	Jan-Jun	263	566	53%
	Jul-Dec	350	690	49%
	Jan-Dec	613	1,256	51%
2003	Jan-Jun	336	616	45%
	Jul-Dec	397	680	42%
	Jan-Dec	733	1,296	43%
2004	Jan-Jun	293	531	45%
	Jul-Dec	472	711	34%
	Jan-Dec	765	1,242	38%

Note: Pollock catches (thousands of tons) are as reported by at-sea observers only, 2004 data are preliminary.

An additional goal for minimizing the potential for impacting the sea lion population is to disperse the fishery throughout more of the pollock range on the eastern Bering Sea shelf. While the distribution of fishing during the A season is limited due to ice and weather conditions, there appears to be some dispersion to the northwest area (Fig. 1.2).

Seasonal TAC releases were intended to disperse the fishery throughout more of the year. Prior to the increased sea lion conservation measures, the fishery was concentrated in 2 seasons, each approximately 6 weeks in length in January-February, and September-October; 94% of the pollock fishery occurred during these four months, with 45% in January-February and 49% in September-October.

Catch data

Significant quantities of pollock are discarded and must be taken into account in estimation of population size and forecasts of yield. Observer length frequency observations indicated that discarded pollock include both large and small pollock. Since observers usually sample the catch prior to discarding, the size distribution of pollock sampled closely reflects that of the actual *total* catch. Discard data as compiled by the NMFS Alaska Regional Office have been included in estimates of total catch since 1990.

Pollock catch in the eastern Bering Sea and Aleutian Islands by area from observer estimates of retained and discarded catch, 1991-2002 are shown in Table 1.2. Since 1991, estimates of discarded pollock have ranged from a high of 9.1% of total pollock catch in 1992 to a low of 1.3% in 2001. These recent low values reflect the implementation of the Council's Improved Retention and Improved Utilization program. Discard rates are likely affected by the age-structure and relative abundance of the available population. For example, if the most abundant year class in the population is below marketable size, these smaller fish may be caught incidentally. With the implementation of the AFA, the fleets have more time to pursue the sizes of fish they desire since they are guaranteed a fraction of the quota. In addition, several vessels have made gear modifications to avoid retention of smaller pollock. In all cases, the magnitude of discards is accounted for within the population assessment and for management (to ensure the TAC is not exceeded).

We estimate the catch-at-age composition using the methods described by Kimura (1989) and modified by Dorn (1992). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: *i*) INPFC area 51 from January - June; *ii*) INPFC area 51 (east of 170°W) from July -December; and *iii*) INPFC area 52 (west of 170°W) from January - December. This method was used to derive the age compositions from 1991-2002 (the period for which all the necessary information is readily available). Prior to 1991, we used the same catch - age composition estimates as presented in Wespestad *et al.* (1996).

The time series of the catch proportions-at-age suggests that during 1999-2003 a broad range of age groups were harvested with 2003 data showing a shift to a fairly even distribution of age 3-7 year old pollock (Fig. 1.7). The values used in the age-structured model are presented in Table 1.3. Since 1999 the observer program adopted a new sampling strategy for lengths and age-determination studies. Under this scheme, more observers collect otoliths from a greater number of hauls (but far fewer specimens per haul). This has improved the geographic coverage but lowered the total number of otoliths collected. Previously, large numbers were collected but most were not aged. The sampling effort for lengths has decreased since 1999 but the number of otoliths processed for age-determinations increased (Table 1.4). The sampling effort for pollock catch, length, and age samples by area appear to be relatively proportional (Fig. 1.8). This indicates that length measurements and otolith collections are consistent relative to catch locations.

Resource surveys

Scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The following table documents annual research catches (1977 - 2004) from NMFS surveys in the Bering Sea and Aleutian Islands Region (tons):

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Bering Sea	15	94	458	139	466	682	508	208	435	163	174	467	393	369
Aleutian Is.				193		40	454			292				

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Bering Sea	465	156	221	267	249	206	262	121	162	164	149	179	236	Na
Aleutian Is.	51			48			36			40		79		Na

Since these values represent extremely small fractions of the total removals (~0.02%), they are not explicitly added to the total removals by the fishery.

Bottom trawl surveys

Trawl surveys have been conducted annually by the AFSC to assess the abundance of crab and groundfish in the Eastern Bering Sea. Bottom trawl surveys are considered to assess pollock from the bottom to 3 m off bottom. Until 1975 the survey only covered a small portion of the pollock range. In 1975 and since 1979, the survey was expanded to encompass more of the EBS shelf occupied by pollock. The level of sampling for lengths and ages in the bottom-trawl survey is shown in Table 1.5.

Since 1983 the biomass estimates have been relatively high and showed an increasing trend through 1990 (Table 1.6). Between 1991 and 2004 the bottom trawl survey biomass estimate has ranged from 2.2 to 8.51 million t. The 2004 estimate is 3.75 million tons, a substantial drop from the 2003 estimate of 8.14 million tons but similar to the model estimate for the BTS in 2003 (4.18 million tons). The high 2003 survey estimate was partly due to a large catch of pollock in a survey tow near Amak Island (northeast of Unimak Island) in the southeastern part of the survey area. The surrounding area was opportunistically observed with a recording echo-sounding device and confirmed that large quantities of pollock were around this region. Omitting the largest tow from the survey calculations nonetheless still resulted in a large biomass estimate (at around 6.5 million tons). The time-series of survey estimates suggest an increasing trend since about 1997 but with the 2003 estimate having an extremely large variance (Fig. 1.9). This high variance tempers somewhat the optimistic survey estimate (compounded with issues related to the warm bottom temperature presented below). In general, the interannual variability of survey estimates is due to the effect of year class variability. Survey abundance-at-age estimates reflect the impact of this variability (Fig. 1.10). Other sources of variance may be due to unaccounted for variability in natural mortality and movement. For example, some strong year classes appear in the surveys over several ages (e.g., the 1989 year class) while others appear at older ages (e.g., the 1992 year class). This suggests that the age-specific spatial distribution of pollock available to bottom-trawl gear is variable.

In 2004 the highest pollock concentrations from the bottom-trawl survey were to the west of the Pribolof Islands and in the northwest portion of the survey area (Fig. 1.11). This differed from the pattern observed in 2003 in which high concentrations were observed in the middle shelf region and moderate concentrations of pollock at the shelf break.

The survey age composition information provides insights on temporal patterns in length-at-age. In particular, when converted to weights-at-age it appears that in recent years the average size (ages 4-8) has recovered and is now above average compared with the below-average observed from 1995-2002 (Fig. 1.12). Since 1982, the pattern in size at age shows a regular periodic trend about every 10 years. This pattern seems to be inversely related (approximately) to pollock abundance and suggests that density dependent processes may be involved.

As in the past few assessments, analysis using survey data alone were conducted to evaluate mortality patterns. Cotter et al. (2004) promote this type of analyses as having a simple and intuitive appeal and is independent of population scale. This simple approach involves regressing the log-abundance of age 6 and older pollock against age by cohort. The negative values estimated for the slope are estimates of total annual mortality. Age-6 was selected because younger pollock are still recruiting to the bottom trawl survey gear. A key assumption of this analysis is that all ages are equally available to the gear. Total mortality by cohort seems to be variable (unlike the example in Cotter et al., 2004) with lower mortality overall for cohorts during the 1990s (Fig. 1.13). Total mortality estimates by cohort are difficult to interpret—here we take them as some form of average mortality over the life of the cohort (since we know that harvest rates varied from year to year). The low values estimated from some year classes, namely the 1990-1992 cohorts, could be due to the fact that there are fewer age-groups (6, 5, and 4, respectively) in the regressions or that these age groups have only recently become available to the survey (i.e., that the availability/selectivity to the survey gear has changed for these cohorts). Alternatively, it may suggest some net immigration into the survey area or a period of lower natural mortality. In general, these values are consistent with the types of values obtained from within the assessment models for total mortality (though the model values tend to be somewhat higher, averaging about 0.5 for these cohorts while the catch-curve analyses the mean total mortality is 0.33 with a CV of 34%).

Effect of temperature

For the past several years the effect of bottom temperature on pollock habitat relative to the standard survey area has been evaluated. Conceptually, the idea is that if the survey area is constant yet the preferred habitat for pollock varies within that area, then some index that causes this variability should improve the reliability of the survey to index the population. Previously, temperature was shown to affect the proportion of the stock that is within or outside of the standard survey area. The recent temperature pattern continues to be relatively warm, especially compared to the 1999 values (Fig. 1.14). These patterns were further examined by comparing pollock density with selected on-bottom isotherms (Fig. 1.15). The temperatures in 2004 were slightly colder than 2003 with the zero-degree isotherm ("cold pool") extending to just south of St. Mathews Island.

Echo-integration trawl (EIT) surveys

Whereas bottom trawl surveys are conducted annually and assess pollock from the bottom to 3 m off bottom, EIT surveys have been conducted approximately triennially since 1979 to estimate pollock in midwater from near surface to within 3 m of bottom (Honkalehto et al. 2002a). In summer 2004 NMFS conducted an EIT survey that extended into the Russian zone (Honkalehto et al. 2004). The USEEZ biomass estimate from this survey was 3.31 million tons, down from 3.6 million tons estimated in 2002 but close to the average estimated by this survey since 1982 (3.36 million tons; Table 1.6). The midwater (near surface to 3 m off bottom) biomass estimate for the Russian EEZ was 0.36 million t—approximately 10% of the total survey area biomass. The EIT survey estimates included population numbers at age (as derived from using an age-length key based on 2004 BTS data). These preliminary 2004 estimates indicated a relatively abundant 2000 year-class (Fig. 1.16). The number of trawl-hauls, and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.7.

Proportions of pollock biomass estimated east vs. west of 170º W, and inside vs. outside the sea lion conservation area (SCA), are about the same for summer EIT surveys conducted from 1994 to 2004 (Table 1.8). Compared to 2002, the relative abundance of pollock was much greater in the NW region of the survey area with concentrations of pollock extending to the convention line (US-Russia boundary) and beyond (Fig. 1.17). The NW:SE portioning of biomass in 2004—though different from that in 2002—was closer to the distribution observed in historical surveys 1994-2000 (Table 1.8).

Analytic approach

Model structure

This age-structured model was first introduced in the 1996 SAFE (Ianelli 1996) and was compared with the cohort-analysis method that had been used extensively for pollock in past years. Since the cohort-analyses methods can be thought of as special cases of this analysis (e.g., as shown in Ianelli 1997 and as in Model 3, current assessment). The statistical age-structured approach has also been documented from analyses performed on simulated data for the Academy of Sciences National Research Council (Ianelli and Fournier 1998). Changes from last year's analyses include:

- The 2004 EBS bottom trawl survey estimate of population numbers-at-age was included.
- The 2004 EBS EIT survey estimate of population numbers-at-age was included (numbers-at-age derived using the 2004 BTS age-length key).

The technical aspects of this model are presented in the attached section titled "Model Details" and have been presented previously (Ianelli 1996, and Ianelli and Fournier 1998). Briefly, the model structure is developed following Fournier and Archibald's (1982) methods, with a number of similarities to Methot's extension (Methot 1990). We implemented the model using automatic differentiation software developed as a set of libraries under the C++ language.

Parameters estimated independently

Natural Mortality and maturity at age

We assumed fixed natural mortality-at-age values based on studies of Wespestad and Terry (1984). These provide estimates of M=0.9, 0.45, and 0.3 for ages 1, 2, and 3+ respectively. These values have been used since 1982 in catch-age models and forecasts and appear to approximate the true rate of natural mortality for pollock. Studies on multi-species models of the EBS and GOA that include pollock suggest that natural mortality may be considerably higher when predators are taken explicitly into account (Livingston and Methot 1998, Hollowed et al. 2000, Livingston and Jurado-Molina 2000, Jurado-Molina et al., In Review).). Their results concluded that when pollock consumption by predators (e.g., Steller sea lions, Pacific cod) is accounted for, "natural mortality" was considerably higher than the values used here. Specifying a conservative (lower) natural mortality rate is more precautionary (Clark 1999).

Maturity at age was assumed the same as that given in Wespestad (1995) which dates back to Smith (1981). This was shown to be consistent with maturity observed in winter surveys in recent years. Pollock reproductive studies are continuing and will be an active study area with sample collections planned for future winter surveys and fishing operations. Values currently in use are given here together with the baseline assumption of natural mortality-at-age:

Age	1	2	3	4	5	6	7	
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	
Prop. Mature	0.000	0.008	0.290	0.642	0.842	0.902	0.948	
Age	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
M	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop. Mature	0.964	0.970	1.000	1.000	1.000	1.000	1.000	1.000

Currently, there are several research projects being undertaken to better understand the reproductive ecology of pollock. These include industry-cooperative research to obtain fine-scale spatial and temporal patterns during the late winter and early spring season. In 2002 and 2003 a total of 10,197 samples were taken for maturity stage and gonad weight from 16 different vessels. Additionally, 173 histological samples are being processed to evaluate the potential to use maturity state together with GSI (gonad weight relative to body weight) to determine proportion mature at length. This research has recently been completed by a graduate student at the University of Alaska Fairbanks, Juneau. Preliminary indications based on the maturity-at-length samples (converted to age via a fishery-derived age-length key from the same seasons and area) suggest similar results to the maturity-at-age schedule assumed for this assessment (Stahl, 2004).

Length and Weight at Age

Length, weight, and age data have been collected extensively for pollock. Samples of length-age and weight-length data within each stratum indicate growth differences by sex, area, and year class. General patterns have been that pollock in the northwest area are slightly smaller at age than in the southeast. Since our estimates of harvests-at-age are stratified by area (and season), these differences are taken into account before analyses within the model. For the fishery, we use year (when available) estimates of average weights-at-age as computed from the fishery age and length sampling programs. These values are shown in Table 1.9 and are important for converting model estimated catch-at-age (in numbers) to estimated total annual harvests (by weight). Since we do not assume a fishery catch-effort relationship explicitly, the fishing mortality rates depend largely on the total annual harvests by weight. For the bottom-trawl and EIT surveys, we tune the model to estimates of total numbers of fish.

Parameters estimated conditionally

For the reference model presented here, 624 parameters were estimated. These include vectors describing recruitment variability in the first year (as ages 2-15 in 1964) and the recruitment deviations (at age 1) from 1964-2004. Additionally, projected recruitment variability was also estimated (using the variance of past recruitments) for five years (2005-2009). The two-parameter stock-recruitment curve is included in addition to a term that allows the average recruitment before 1964 (that comprises the initial age composition in that year) to have a mean value different from subsequent years. Thus, 64 parameters comprise initial age composition, subsequent recruitment values and stock-recruitment parameters.

Fishing mortality is parameterized to be semi-separable. That is, there is a year component and an age (selectivity) component. The age component is allowed to vary over time with changes allowed every three years. The age component is constrained such that it's mean value will be equal to one, this means that it will not be confounded with the time component (see section below titled "Model details"). In addition, we assume that the age-component parameters are constant for the last 4 age groups (ages 12-15). Therefore, the time component of fishing mortality numbers 42 parameters (estimable since we place low variance on the likelihood component on the total catch biomass) and the added age-time component of variability results in an 11x14 matrix of 154 parameters. This brings the total fishing mortality parameters to 196. Please note however, that in standard cohort analyses such as that of Pope (1972) the number of parameters for a similarly dimensioned problem would be 39x15 or 585 fishing mortality parameters. Of course in a VPA, these parameters are not estimated statistically, rather implicitly using an algorithm that assumes no errors in the total catch-at-age.

For the bottom trawl survey, a similar parameterization for the selectivity-at-age estimates includes an overall catchability coefficient, age and year specific deviations in the average availability-at-age which totals 72 parameters for these data (for the logistic time-varying selectivity curves). This estimate is conditioned on the model structure and available data. Recent studies on experimental approaches to evaluating the actual survey catchability have, for example, shown that pollock do not tend to be "herded" in response to stimuli produced by the doors, mud clouds, or bridles of survey trawls (Somerton 2004). These types of considerations can be important to qualify model estimates. For the EIT survey, which began in 1979, there are 286 parameters describing age-time specific availability. Estimates for changes in EIT selectivity sometimes occur for years when the survey was not conducted. This increases the number of parameters we estimate, but avoids problems associated with surveys occurring on irregularly spaced intervals. The idea of estimating these changes is to allow some continuity in unaccounted-for variability of fish available to our survey gear. That is, we expect things to change in this regard but our null hypothesis is that the survey operation is constant with respect to relative changes in age class availability.

As last year, we evaluate the effect of temperature (T_t) on the survey catchability in year *t* as:

$$q_t = \mu_q + \beta_q T_t$$

where μ_q is the mean catchability and β_q represents the slope parameter. The time series of temperature (Fig. 1.14) is used in Model 4 (which, for the model was normalized to have a mean value of zero).

For all other models, the catchability coefficient for the bottom-trawl survey is estimated in the same manner as is done for the other two indices (early CPUE data and the EIT survey). These three catchability coefficients (one for each index) are estimated as free parameters.

Finally, three additional fishing mortality rates are estimated conditionally. These are the values corresponding to the $F_{40\%}$, $F_{35\%}$ and the $F_{30\%}$ harvest rates. These rates satisfy the constraint that given selectivity-at-age vector (we used the mean selectivities based on model configuration), proportion-mature-at-age, natural mortality rate, and weight at age, there are unique values that correspond to the fishing mortality rates.

The likelihood components can thus be partitioned into the following groups:

- Total catch biomass (Log normal, σ=0.05)
- Log-normal indices of abundance (bottom trawl surveys assume annual estimates sampling error, as represented in Fig. 1.9, for the EIT and CPUE indices values of σ=0.2 were assumed)
- Fishery and survey proportions-at-age estimates (robust quasi-multinomial with effective sample sizes presented in Table 1.10).
- Selectivity constraints: penalties/priors on age-age variability, time changes, and decreasing (with age) patterns
- Stock-recruitment: penalties/priors involved with fitting a stochastic stock-recruitment relationship within the integrated model.

Model evaluation

At the December 2003 meeting, the NPFMC's SSC requested that additional investigations on the effect of age-determination error be evaluated. Two alternative model configurations were included to illustrate sensitivity to these assumptions. In one (Model 2) ageing-error is assumed to be estimated as in Ianelli et al. (2003) where the percent-agreement between "age readers" was statistically evaluated to provide an estimate of the age assignment probability distribution. The ages were assumed to be unbiased. In the other configuration (Model 3), it was assumed that the catch-at-age was measured without errors (using the same approach as in Butterworth et al., 2004).

A list of the models presented includes:

Model 1 **Reference model,** future selectivity based on most recent (3-year) estimate (short-term selectivity estimate). This was the model configuration selected by the Council for ABC recommendations in last year's assessment.

Model 2 As reference model but with ageing error included.

Model 3 Fit fishery catch-at-age data exactly (VPA-like model).

Model 4 As reference model but with bottom-trawl survey catchability including an environmental covariate (average summer bottom temperature in the EBS).

Model 5 As reference model, but with bottom-trawl survey catchability fixed at 1.0.

Model 6 As Model 5 but estimating natural mortality.

These models can be summarized as follows:

Model	Description
1	Reference model
2	Employ re-estimated age-error matrix
3	Fit fishery catch-age precisely (VPA-like assumption)
4	Bottom temperature a covariate with survey catchability
5	Bottom-trawl survey catchability fixed at 1.0.
6	Estimate natural mortality

The reference model can be characterized as one that includes a moderate number of stochastic processes. These are principally changes in age-specific availability over time for survey and fishery gears and recruitment variability. As specified, these processes involve a large number of parameters but capture a reasonable amount of the overall uncertainty.

As in previous years, the stock-recruitment curve fitting for the Reference model (Model 1) is using only the period from 1978-2004. Previous analyses using alternative stock-recruitment forms and periods gave consistently more optimistic scenarios than the Reference Model presented here. We selected the current stock-recruitment relationship and period for estimation because we believe it results in more conservative estimates of stock productivity while retaining reasonable properties (i.e., relatively good fits to the observed data).

In Model 2 the estimated errors in age-determination process (Ianelli et al., 2003) was included. Results from this model provided a slightly improved fit (i.e., a lower –ln(likelihood) function; Table 1.11). As expected, the recruitment variability increased (from 62% CV to 73%) with the ageing error included. The estimated stock size was slightly lower with this model compared with Model 1 but the reference fishing mortality rates were similar (Table 1.12). In Model 3 the effect of fitting the catch-at-age data precisely was evaluated (similar to a VPA-model). This resulted in an increase of model parameters from 624 to 910 but only improved the overall fit by 108 likelihood units and a pattern of fishery selectivities (also referred to as "partial F's") that were highly variable over time (Fig. 1.18).

One concern that frequently arises in the EBS pollock stock assessment is the effect of Russian catches adjacent to the US-Russia convention line (maritime boundary). This effect was evaluated last year (Ianelli et al. 2003) and results indicated that the added mortality of EBS pollock incurred in the Russian zone inflated the biomass estimates.

Pollock distribution appears to be affected by ambient temperature (e.g., Fig. 1.15), it follows that bottom temperature will affect survey catchability/vulnerability (Model 4). A slight positive trend was detected between temperature and survey catchability (β=0.027 and standard error 0.124; Fig. 1.19). As before, the significance of this fit is low given this standard error, and the overall fit is only slightly better (the -lnL improves by 0.02 units compared to Model 1; Table 1.11).

Bottom temperature alone does not provide a strong indicator for changes in survey availability. Presumably factors affecting this covariate are complicated by the current age-structure of the population (younger pollock may be more or less sensitive than older pollock) and perhaps the vertical distribution of pollock. For contrast, in Model 5 we constrained survey catchability to be exactly equal to one. This resulted in a worse fit to the data and a much higher biomass estimate.

Model estimates of survey catchability that are greater than 1.0 may seem counterintuitive, given that we expect the bottom-trawl gear to be missing pollock that are up in the water column and outside of the survey area. However, recall that there is a significant age-component of catchability and that estimates can be an artifact of model mis-specification (e.g., of constant natural mortality over time). For example, factoring the age-effect (selectivity) of the survey gear and considering the average biomass of pollock age 5 and older, the survey catchability is slightly less than 1.0. Considering age 3 and older pollock biomass, the average catchability by the survey is about 0.7. This effect is because younger pollock appear to be less available to bottom-trawl survey gear.

In Model 6 we evaluated the ability of our model to estimate natural mortality (with survey catchability fixed at a value of 1.0). The parameterization was specified for age-3 and older as Me^{ρ} where the estimate was (from *M=0.3*): $\hat{\rho}$ =0.048 with a standard error of 0.080 (giving Me^{ρ} =0.315). In recent past assessments this estimate was lower reflecting (possibly) the fact that some year-classes (e.g., the 1992 year-class) have persisted above expectations. In 2004 the 1992 year class abundance estimate was closer to expected levels and has moderated the low total mortality observed in the catch-curve analysis (presented above).

Based on the examinations of the alternative models presented here (and also over those that were run but not presented) Model 1 was selected as an appropriate configuration since it encompasses a wide range of uncertainties about the stock status. Adding in the effect of ageing error (Model 2) gave a similar fit to the data and did not appreciably affect the model results. One problem with using the estimated age-imprecision matrix is that it may not reflect the full process of age-determination. The data tends to show strong year-classes at greater levels than expected given the estimates of age-determination imprecision. That is, the age readers may tend to age questionable samples into the most commonly found age group. Since this type of error is difficult to quantify (unlike ageing imprecision based on between reader-agreement), selecting Model 2 as an alternative configuration may simply be introducing a different source of error. Including Russian catches explicitly into the assessment (Ianelli et al., 2003) inflated the biomass considerably but had little effect on resource resiliency estimates. Fitting the catch-at-age data precisely (Model 3) resulted in the expected benefit to fitting the data, but as noted above, was poorly justified based on the increased number of estimated parameters. The effect of bottom temperature (Model 4) was minor. Model 5 (bottom-trawl survey catchability fixed at 1) has precedence from other assessments but provides a somewhat more optimistic view of the stock condition compared to Model 1. For this reason, Model 1 is favored as being more conservative and more appropriately acknowledges problems with assuming a value of survey catchability. Allowing natural mortality to be estimated freely in Model 6 confirms somewhat the catch-curve analysis presented above and compared with past years, suggests that natural mortality is slightly higher than that used in the model. Ideally, a set of objective criteria to select among models would be preferred. Since the models developed here are fundamentally Bayesian, model selection process could follow an analyses of Deviance Information Criterion (DIC; Spiegelhalter et al., 2002). However, this approach requires computing large numbers of simulations for each alternative which would allow estimation of "effective number of parameters." Research on implementing this type of analyses is continuing but will require some further modifications to the model structure (specifically, in how the selectivity is modeled and in the catch-equation approach). A completely alternative approach would be to simplify the assessment model approach used for estimating ABC, and do a full management strategy evaluation (MSE) on the simplified approach. This is another area of active research within the AFSC (see below).

Biomass estimates from different surveys often differ substantially from those based on model results. For example, the "total age-3+ biomass" estimates for 2004 are over 9.8 million tons compared to the bottom-trawl survey biomass estimate of slightly more than 3.75 million tons. Such a difference can be attributed to three main factors: **weight** (averaged by age), **time** (within a year), and **selectivity/availability**. The effects of these factors were presented in detail in previous assessments (Ianelli et al. 2001). The same interpretation issues apply in the current study—namely that "biomass estimates" depend on the ages considered (and the catchability implications from surveys), the time of year, and the average weights-at-age estimates.

Results

Several key results have been summarized in Tables 1.12 & 1.13. This year's estimate of the 2000 year-class is greater than estimated in last year's assessment (2003) but the biomass estimates of all other ages is lower due to the 2004 survey estimate (Fig. 1.20). This figure also shows that the projected 2005 estimates of biomass by age group is considerably below the recent averages for most age groups (except 5 and 13 yr-old pollock). The 2000 year class appears to be above average and represents a significant biomass component of the stock. The decline in the overall level of biomass estimated this year is in part due to the low survey estimate in 2004 (3.75 million tons) relative to the 2003 estimate of 8.14 million tons. In general, the pollock stock tends to have periods of either above-average abundance of young fish and below average abundance of middle-age fish or the reverse (Fig. 1.21).

The estimated Model 1 fishery selectivity pattern changes over time to become slightly more dome-shaped during the 1990s (Fig. 1.22). This may have coincided with the move to pelagic-only trawl gear as larger (older) fish tend to be more bottom-oriented. Model 1 fits the fishery age-composition data quite well and strong year classes are clearly evident (Fig. 1.23). The fit to the early Japanese fishery CPUE data (Low and Ikeda, 1980) is consistent with the populations trends for this period (Fig. 1.24).

Selectivity was allowed to vary slightly over time for both surveys. This was done to account for potential changes in fish distribution. For example, it seems reasonable to assume that the presence of 1-year-olds available to the bottom-trawl gear on the shelf might be variable, even when the abundance is the same (Fig. 1.25). The bottom trawl survey age composition data are somewhat inconsistent in 2000-2003. The abundance of the 1995 year class has apparently increased while the proportion of the 1996 year class in these years was lower than expected (Fig. 1.26). Currently, the 2000 year class is important to the fishery in the near-term and will require close monitoring.

The Model 1 fit and estimated selectivity for the EIT survey data show a change in selectivity pattern over time (Fig. 1.27). This may be due in part to changes in pollock distribution (as the overall densities changed and also to the fact that large numbers of 1 and 2-year old fish were apparent in the survey during the early surveys. Also, the number of hauls sampled has generally increased over time—presumably this trend affects the overall estimate of the age composition of pollock available to the survey (e.g., by increasing the chance of sampling the less common larger pollock). These patterns are also illustrated in the model fit to the EIT survey age composition data (Fig. 1.28). The proportions at age observed in the survey are generally consistent with what appeared later in the bottom-trawl survey and fishery. Alternative configurations for modeling the time-trend in EIT catchability at age were explored. In particular, the influence of age-1 abundance (e.g., in the 1997 survey) was evaluated by tuning the model with one-year olds excluded. This resulted in better fits but the effect on the overall model results was minimal.

Estimated numbers-at-age for Model 1 are presented in Table 1.14 and estimated catch-at-age presented in Table 1.15. Estimated summary biomass (age 3+), female spawning biomass, and age-1 recruitment for Model 1 is given in Table 1.16.

Uncertainty computations are a central part of the analyses presented in this assessment. In the past year, development of Bayesian methods has continued. Often with highly non-linear models, the multidimensional shape of the posterior distribution can be highly curved and present problems when expressing approximations to marginal distributions (e.g., as we do here via the Delta-method propagation-of-errors to obtain variance estimates for management quantities of interest). To explore this property, we computed the joint distribution based on 2 million Monte-Carlo Markov Chain simulations drawn from the posterior distribution. The chain was thinned to reduce potential serial correlation to 5,000 parameter "draws" from the posterior distribution. Selected model parameters (Model 1) are plotted pair-wise to provide some indication of the shape of the posterior distribution (Fig. 1.29). In general, the model given the available data appears to be quite well behaved (clusters of parameters do not appear to follow strange curved or skewed tear-drop shapes). In terms of policy evaluation, projected values (for each "sample" from the posterior) with a fixed catch of 1.3 and 1.5 million tons indicate that the probability that the current stock size is below the (uncertain) $B_{35\%}$ level is quite low. However, by 2007, the expectation is that the stock size will be close to the $B_{35\%}$ stock size level for both constant-catch scenarios. In the longer term, these constant catch policies are expected to have biomass levels above the $B_{35\%}$ level but with considerable uncertainty based on projections to 2009 (Fig. 1.30).

The NPFMC Groundfish Plan Team suggested showing a figure depicting future catches (using one or more of the standard harvest scenarios) rather than just constant catch scenarios. Also, the Plan Team asked that the assessment authors consider presenting confidence intervals around the recommended ABC. These are presented in Figure 1.31.

Abundance and exploitation trends

The eastern Bering Sea bottom trawl survey estimates exhibited an increasing trend during the 1980s, were relatively stable from 1991 to 1995, and decreased sharply in 1996 but rose slightly in 1997 and then substantially in 1999 - 2003. This may be due, in part, to age-related distribution changes within the pollock population. Results from combined bottom trawl and EIT surveys, which more fully sample the population, have shown that older pollock are more vulnerable to bottom trawls than younger pollock (e.g., Figs. 1.25 and 1.26).

Current "exploitable" biomass estimates (ages 3 and older) derived from the statistical catch-age model suggest that the abundance of eastern Bering Sea pollock remained at a fairly high level from 1982-88, with estimates ranging from 10.5 to 12.5 million t. Peak biomass occurred in 1985 and declined to about 6 million t by 1991. Since then, the age 3 and older biomass has increased, and recently been variable around 10-11 million tons[1].

Historically, biomass levels have increased from 1979 to the mid-1980's due to the strong 1978 and relatively strong 1982 and 1984 year classes recruiting to the fishable population (Table 1.17, Fig. 1.32). From 1985-86 to 1991 the fishable stock declined as these above average year classes decreased in abundance with age and were replaced by weaker year classes. In 1992 an upturn in abundance began with the recruitment of a strong 1989 year class and peaked around 1995. With the apparent high abundance of the 2000 year class, the population remains at relatively high levels. However, since the 1996 year class is now largely gone, the extent that the fishery will rely on the 2000 year class and the strength of subsequent year classes will determine the short term population trend. The short-term indications are that the stock will drop below $B_{40\%}$ by 2006 and be near the B_{msy} level by 2007.

Retrospectively, this year's assessment is very similar to last year prior to 1998 (Table 1.17). However, the recent biomass estimates are substantially lower than that estimated in 2003 (Fig. 1.33). This may be attributed to the addition of a substantially lower survey estimate for 2004 and the addition of this year's EIT data. The 2005 stock size is estimated to be at the lowest level since 1992.

The abundance and exploitation pattern estimated from Model 1 shows that the spawning exploitation rate (SER, defined as the percent removal of the female spawning biomass in any given year) has averaged about 13% in the past 10 years (Fig. 1.34). This compares to an overall average SER of 17% (1964 – 2004). The observed variation in pollock abundance is primarily due to natural variation in the survival of individual year classes. These values of SER are relatively low compared to the estimates at the MSY level (~30%).

One way to evaluate past management and assessment performance is to plot estimated fishing mortality relative to the (current) maximum permissible values. For EBS pollock, we computed the reference fishing mortality as from Tier 3 (unadjusted) and calculated the historical values for $F_{40\%}$ (since selectivity has changed over time; Fig. 1.35, top panel). Since 1977 the current estimates of fishing mortality suggest that during the early period, harvest rates were above $F_{40\%}$ until about 1981. Since that time, the levels of fishing mortality have averaged about 51% of $F_{40\%}$ (Fig. 1.35, bottom panel).

Recruitment

Recruitment of pollock is highly variable and difficult to predict. It is becoming clear that there is a great deal of interannual variation in the distribution of pre-recruit pollock, both in depth and geographic area. To some extent, our approach takes this into account since age 1 fish are included in our model and data from both the EIT and bottom trawl survey are used. In earlier assessments (prior to 1998), the primary measure of pollock recruitment had been the relative abundance of age 1 pollock (or pollock smaller than 20 cm when age data are unavailable) in the annual eastern Bering Sea bottom-trawl survey. Also, bottom-trawl survey estimates of age 1 recruitment, when regressed against age 3 pollock estimates from catch-age models, indicate a linear relationship. This had been used to project age 3 numbers in population forecasts. Our method does not require external regressions since the necessary accounting is done explicitly, within a standard age-structured model. The key advantage in our approach is that the observation and process errors are maintained and their effect can be evaluated.

[1] Please refer to Ianelli et al. (2001) for a discussion on the interpretation of age-3+ biomass estimates.

It appears that the annual bottom trawl survey does not fully cover the distribution of age 1 pollock. This is especially evident for the 1989 year class that the survey found to be slightly below average, but upon recruitment to the fishery, was a very strong year class. It appears that a significant amount of this year class was distributed in the Russian EEZ—beyond the standard survey area—or unavailable to bottom trawl gear (perhaps in mid-water). In 1996, Russian scientists reported the 1995 year class to be strong, but it appeared to be below average in the U.S. survey. However, in the 1997 EIT survey the 1995 year class was abundant adjacent to the Russian EEZ.

The coefficient of variation or "CV" (reflecting uncertainty) on the strength of the 1996 year class is about 15% for Model 1. Currently, the 2000 year class appears to be slightly above average and the 1999 year class appears to be slightly above average; Fig. 1.36). As more survey observations on these year classes occur, the precision of these estimates is expected to increase.

Projections and harvest alternatives

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Estimates of reference points related to maximum sustainable yield (MSY) are currently available. However, the extent of their reliability is questionable. We therefore present both reference points for pollock in the BSAI to retain the option for classification in either Tier 1 or Tier 3 of Amendment 56. These Tiers require reference point estimates for biomass level determinations. For our analyses, we selected the following values from Model 1 results computed based on recruitment from post-1976 spawning events:

$B_{100\%}$ = 7,232 thousand t female spawning biomass[2]

$B_{40\%}$ = **2,645** thousand t female spawning biomass

$B_{35\%}$ = **2,314** thousand t female spawning biomass

B_{msy} = **2,226** thousand t female spawning biomass

Specification of OFL and Maximum Permissible ABC

For Model 1, the year 2004 spawning biomass is estimated to be 2,706 thousand tons (at the time of spawning, assuming the stock is fished at F_{msy}). This is above the B_{msy} value of 2,226. Under Amendment 56, Tier 1a, the harmonic mean value is considered a risk-averse policy provided reliable estimates of F_{msy} and its pdf are available. To provide the NPFMC with an alternative, an exploitation-rate type value that corresponds to the F_{msy} levels was applied to age 3+ biomass.

Corresponding values under Tier 3 are 2,871 thousand tons for year 2005 spawning values (under $F_{40\%}$ policy). This is above the $B_{35\%}$ value of 2,314 . The OFL's and maximum permissible ABC values by both methods are thus:

	OFL	Max ABC

[2] Note that another theoretical "unfished spawning biomass level" (based on stock-recruitment relationship $\tilde{B}_0$) is somewhat lower (5,671t).

Tier 1a	**2,104 thousand t**	**1,962 thousand t**
Tier 3a	**2,325 thousand t**	**1,897 thousand t**

ABC Considerations

Currently, the biomass of eastern Bering Sea pollock appears to be decreasing. The total begin-year age-3+ biomass in 2005 is projected to be about 8,573 thousand t. The estimated female spawning biomass projected to the time of spawning in the year 2005 is about **2,871** thousand tons, well above of the $B_{40\%}$ level of **2,645** thousand tons. Also, this stock size is projected to be above the $B_{35\%}$ and B_{msy} levels (**2,314** and **2,226** respectively; Fig. 1.37).

For 2005, maximum permissible ABC alternatives based on the $F_{40\%}$ and harmonic-mean F_{msy} are 1,897 and 1,962 thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value) as shown in Table 1.13 for Model 1. Current estimates of recruitment (e.g., the 2000 year class) are appear to be above average. Hence, short-term projections predict that the spawning stock is likely to drop below the $B_{35\%}$ and approach B_{msy} levels. There is nothing intrinsically wrong with having the population drop below the optimal level (since under perfect management, it is expected to be below the target exactly half of the time). However, choosing a harvest level that reduces this likelihood could 1) provide stability to the fishery; 2) provide added conservation given the current Steller sea lion population declines; and 3) provide added conservation due to uncertain levels of removals from Russian waters. Therefore it seems prudent to recommend a harvest level lower than the maximum permissible values. As an example, under constant catch scenarios of 1.5 and 1.3 million tons, the stock is expected to remain above the B_{msy} level (Fig. 1.38). Since catch levels (TAC) are likely to remain below 1.5 million tons for pollock due to the multispecies considerations, and since evaluations of multispecies MSY (see ecosystem considerations section) suggest that 2 million metric tons is a conservative value for OY, these projections are considered most important for evaluating future stock conditions. An ABC equal to the $F_{40\%}$ value for 2005 (**1,897 thousand t**) is recommended. This is below the maximum permissible Tier 1a level and was selected in order to be more conservative. A lower ABC level is more precautionary and will provide a more gradual decline in spawning biomass as it approaches the $B_{35\%}$ level. Note that these levels are designed to provide conservation guidelines for individual species but recognizes that all groundfish fisheries are managed as part of a multispecies complex.

Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2004 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow (A "*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2005 recommended in the assessment to the *max* F_{ABC} for 2005. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2000-2004 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to FOFL. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2005 or 2) above ½ of its MSY level in 2005 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)

Scenario 7: In 2005 and 2006, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2017 under this scenario, then the stock is not approaching an overfished condition.)

Projections and status determination

For the purposes of these projections, we present results based on selecting the $F_{40\%}$ harvest rate as the max F_{ABC} value and use $F_{35\%}$ as a proxy for F_{msy}. Scenarios 1 through 7 were projected 14 years from 2004 (Table 1.18). Under Scenario 1, the expected spawning biomass will decrease to below $B_{35\%}$ then increase to above $B_{40\%}$ by the year 2010 (Fig. 1.37). Under this scenario, the yields are expected to vary between 1.0 – 1.8 million tons. For contrast, the near-term decline in spawning biomass is moderated under the policy (Scenario 5) with no fishing (Fig. 1.39). If the highly conservative fishing mortality levels (estimated from the last 5 years, Scenario 4) are to continue, then the stock is not projected to drop below $B_{35\%}$ in the future (Fig. 1.40).

Any stock that is below its MSST is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest scenarios 6 and 7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2004:

a) If spawning biomass for 2005 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.

b) If spawning biomass for 2005 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2005 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario 6 (Table 1.18). If the mean spawning biomass for 2015 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario 7:

a) If the mean spawning biomass for 2007 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2007 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2007 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2017. If the mean spawning biomass for 2016 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

For scenarios 6 and 7, we conclude that pollock is not below MSST for the year 2005, nor is it expected to be approaching an overfished condition based on Scenario 7.

Other considerations

Localized depletion estimators

Battaile (2004) recently completed research on a detailed study of pollock exploitation patterns in the EBS. He used a DeLury model to investigate potential localized depletion by the fishery. The estimator used the slope of log-CPUE versus cumulative effort, for data from 1995-1999 stratified by small areas, short seasons and years. He found that of 237 depletion estimators, 172 had negative slopes while 65 had positive slopes. Each of these had subsets that were statistically significant (more than expected based on chance alone). Depletion was most easily detected in areas of low abundance and consequently lower catch and effort. Overall, his estimates of depletion were smaller than the overall depletion expected from the estimates of exploitation rates. As noted in Barbeaux et al. (this volume) for the Aleutian Islands, estimators involving CPUE data from a pollock fishery is likely to be problematic due to hyperstability. Nonetheless, there is evidence that pollock can repopulate areas rapidly (Barbeaux and Dorn 2003).

Ecosystem considerations

In general, a number of key issues for ecosystem conservation and management can be highlighted. These include:

- Preventing overfishing;
- Avoiding habitat degradation;
- Minimizing incidental bycatch (via multi-species analyses of technical interactions);
- Controlling the level of discards; and
- Considering multi-species trophic interactions relative to harvest policies.

For the case of pollock in the EBS, the NPFMC and NMFS continue to manage the fishery on the basis of these issues in addition to the single-species harvest approach. The prevention of overfishing is clearly set out as a main guideline for management. Habitat degradation has been minimized in the pollock fishery by converting the industry to pelagic-gear only. Bycatch in the pollock fleet is closely monitored by the NMFS observer program and managed on that basis. Discarding rates have been greatly reduced in this fishery and multi-species interactions is an ongoing research project within NMFS with extensive food-habit studies and simulation analyses to evaluate a number "what if" scenarios with multi-species interactions.

In August 2004, the AFSC convened a working group to conduct and review ongoing research related to Management Strategy Evaluations (MSEs). While evaluation of fishery management strategies has been an ongoing research activity of the AFSC for many years (e.g., the Programmatic Supplemental Environmental Impact Statement (PSEIS) for the BSAI and GOA Groundfish FMPs), part of this work is designed to respond to the NPFMC report recommending that further analyses be pursued (Goodman et al., 2002). At the working group meeting, part of the discussion centered on the use of ecosystem modeling to define alternative reference points. An example of this approach (albeit on simpler terms) would be to use multi-species MSY estimates (e.g., Mueter et al., Ecosystem Considerations section, this volume) to evaluate the effectiveness of the 2.0 million ton OY. They found that the current OY level is likely to be below the multi-species MSY values.

In general, the climatic conditions that may affect the Bering Sea ecosystem have apparently undergone a change since the late 1990s. After spending most of the 1990s in positive mode the Pacific Decadal Oscillation (PDO) shifted to negative in 1998/99. This coincides with cooler-than-average northeastern Pacific surface temperatures and warmer-than-average central Pacific surface temperatures. This negative PDO has apparently continued. Mueter et al. (2004) conducted a comprehensive analysis of climatic variables and evaluated mechanisms that affect pollock recruitment. Their research investigated four hypotheses on factors related to pollock recruitment variability. These are 1) the "cold-pool" hypothesis (the extent of winter ice and subsequent cold pool formation), 2) the "oscillating control hypothesis" (relating pollock survival to characteristic spring blooms and predator abundance, 3) the "stability hypothesis" (related to water column stratification and wind stress), and 4) the "larval transport hypothesis" (related to surface-water advection influencing the degree of spatial separation between juveniles and cannibalistic adults). Their results confirmed previous findings (e.g., larval transport within an assessment model, Ianelli et al. 2001) that environmental indices explain only a small portion of the recruitment variability. However, evaluating these hypotheses will provide important information that will be included in developing operating models for MSEs. For example, they found some support for the oscillating control hypothesis and fairly strong support for their new stability hypothesis. Using historical climate patterns on these variables for conditioning operating models (i.e., specifying alternative hypotheses) is a critical step for refining MSEs. In their study, they found that the cold-pool apparently had negligible effect of concentrating adult and juvenile pollock (and thereby increasing encounter rates and predation). In Model 4 (above), a slight positive (but highly uncertain) relationship between average bottom temperature and survey catchability was observed.

A recent analysis comparing the Western Bering Sea (WBS) with the Eastern Bering Sea using mass-balance food-web models was published this year (Aydin et al., 2002). This study shows that the production in these two systems is quite different. On a per-unit-area measure, the western Bering Sea has higher productivity than the EBS. Also, the pathways of this productivity are different with much of the energy flowing through epifaunal species (e.g., sea urchins and brittlestars) in the WBS whereas for the EBS, crab and flatfish species play a similar role. In both regions, the keystone species are pollock and Pacific cod. Based on the evaluation of the food web using a mass-balance equation, Aydin et al. (2002) found that the EBS ecosystem was relatively mature due to the large number of interconnections.

Ciannelli et al. (2004) present an application of an ecosystem model scaled to data available around the Pribolof Islands region. They applied bioenergetics and foraging theory to characterize the spatial extent of this ecosystem. They compared energy balance, from a food web model relevant to the foraging range of northern fur seals and found that a range of 100 nautical mile radius encloses the area of highest energy balance representing about 50% of the observed foraging range for lactating fur seals. This suggests that fur seals depend on areas outside the energetic balance region. This study develops a method for evaluating the shape and extent of a key ecosystem in the EBS (i.e., the Pribilof Islands). Furthermore, the extent that the pollock fishery extends into northern fur seal foraging habitat (e.g. Robson et al. 2004) will require careful monitoring and evaluation.

Another way of evaluating ecosystem considerations is to look at how the **ecosystem affects the EBS pollock stock** and at how the **EBS pollock fishery affects the ecosystem.** A brief summary of these two perspectives is given in Table 1.19. Unlike the food-web models discussed above, examining predators and prey in isolation may overly simplify relationships. This table serves to highlight the main connections and the status of our understanding or lack thereof. The fishery bycatch estimates of target and non-target species is given in Tables 1.20 & 1.21, respectively.

Summary

Summary results are given in Table 1.22.

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Tables

Table 1.1 Catch from the eastern Bering Sea by area, the Aleutian Islands, the Donut Hole, and the Bogoslof Island area, 1979-2004 (2004 values set equal to TAC). Units are tons. The southeast area refers to the EBS region east of 170W; the Northwest is west of 170W.

	Eastern Bering Sea			**Aleutians**	**Donut Hole**	**Bogoslof I.**
Year	Southeast	Northwest	Total			
1979	368,848	566,866	935,714	9,446		
1980	437,253	521,027	958,280	58,157		
1981	714,584	258,918	973,502	55,517		
1982	713,912	242,052	955,964	57,753		
1983	687,504	293,946	981,450	59,021		
1984	442,733	649,322	1,092,055	77,595	181,200	
1985	604,465	535,211	1,139,676	58,147	363,400	
1986	594,997	546,996	1,141,993	45,439	1,039,800	
1987	529,461	329,955	859,416	28,471	1,326,300	377,436
1988	931,812	296,909	1,228,721	41,203	1,395,900	87,813
1989	904,201	325,399	1,229,600	10,569	1,447,600	36,073[3]
1990	640,511	814,682	1,455,193	79,025	917,400	151,672
1991	653,589	542,056	1,195,645	98,604	293,400	264,760
1992	830,560	559,771	1,390,331	52,352	10,000	160
1993	1,094,431	232,173	1,326,604	57,132	1,957	886
1994	1,152,573	176,777	1,329,350	58,659	NA	566
1995	1,172,304	91,941	1,264,245	64,925	trace	264
1996	1,086,840	105,938	1,192,778	29,062	trace	387
1997	819,888	304,543	1,124,431	25,940	trace	168
1998	965,767	135,399	1,101,166	23,822	trace	136
1999	783,119	206,697	989,816	1,010	trace	29
2000	839,175	293,532	1,132,707	1,244	trace	28
2001	961,975	425,219	1,387,194	824	trace	258
2002	1,159,732	320,463	1,480,195	1,156	trace	NA
2003	1,125,999	364,095	1,490,095	1,653	trace	NA
2004	NA	NA	1,492,000	1,141	trace	NA

1979-1989 data are from Pacfin.

[3] Data may be from September-December only (Data from Jan-Aug were lacking, Honkalehto 1990)

1990-2003 data are from NMFS Alaska Regional Office, includes discards.
2004 EBS catch assuming full TAC will be taken; for Aleutians catch data as of Oct 16, 2004

Table 1.2. Estimated retained, discarded, and percent discarded of total catch in the Aleutians, Northwest and Southeastern Bering Sea, 1991-2002. Units are in tons, SE represents the EBS east of 170° W, NW is the EBS west of 170° W, source: NMFS Blend database.

Area	Year	Discard	Retained	Total	Percent Discard
Aleutian Islands		5,231	93,373	98,604	5.3%
Bogoslof		20,327	295,711	316,038	6.4%
NW	**1991**	48,205	493,852	542,056	8.9%
SE		66,789	586,763	653,552	10.2%
1991 Total		140,572	1,469,716	1,610,288	8.7%
Aleutian Islands		2,982	49,369	52,352	5.7%
Bogoslof		240	1	241	99.6%
NW	**1992**	57,609	502,162	559,771	10.3%
SE		71,195	759,364	830,560	8.6%
1992 Total		132,027	1,310,897	1,442,924	9.1%
Aleutian Islands		1,733	55,399	57,132	3.0%
Bogoslof		308	578	886	34.8%
NW	**1993**	26,100	206,073	232,173	11.2%
SE		83,989	1,010,443	1,094,431	7.7%
1993 Total		112,130	1,272,491	1,384,622	8.1%
Aleutian Islands		1,373	57,286	58,659	2.3%
Bogoslof		11	545	556	2.0%
NW	**1994**	16,083	160,693	176,777	9.1%
SE		88,098	1,064,476	1,152,573	7.6%
1994 Total		105,565	1,283,000	1,388,565	7.6%
Aleutian Islands		1,380	63,545	64,925	2.1%
Bogoslof		267	66	334	80.1%
NW	**1995**	9,715	82,226	91,941	10.6%
SE		87,491	1,084,812	1,172,304	7.5%
1995 Total		98,854	1,230,650	1,329,503	7.4%
Aleutian Islands		994	28,067	29,062	3.4%
Bogoslof		7	492	499	1.4%
NW	**1996**	4,838	101,100	105,938	4.6%
SE		71,367	1,015,473	1,086,840	6.6%
1996 Total		77,206	1,145,133	1,222,339	6.3%
Aleutian Islands		617	25,323	25,940	2.4%
Bogoslof		13	150	163	7.7%
NW	**1997**	22,557	281,986	304,543	7.4%
SE		71,031	748,857	819,888	8.7%
1997 Total		94,217	1,056,316	1,150,533	8.2%
Aleutian Islands		164	23,657	23,822	0.7%
Bogoslof		3	133	136	1.9%
NW	**1998**	1,581	133,818	135,399	1.2%
SE		15,135	950,631	965,767	1.6%
1998 Total		16,883	1,108,239	1,125,123	1.5%
Aleutian Islands		480	529	1,010	47.6%
Bogoslof		11	18	29	38.7%
NW	**1999**	1,912	204,785	206,697	0.9%
SE		27,089	756,030	783,119	3.5%
1999 Total		29,492	961,362	990,855	3.0%
Aleutian Islands		790	455	1,244	63.4%
Bogoslof		20	10	29	66.6%
NW	**2000**	1,941	291,590	293,532	0.7%
SE		19,678	819,497	839,175	2.3%
2000 Total		22,428	1,111,552	1,133,981	2.0%
Aleutian Islands		380	445	824	46.1%
Bogoslof		28	231	258	10.8%
NW	**2001**	2,450	422,769	425,219	0.6%
SE		14,873	947,015	961,889	1.5%
2001 Total		17,731	1,370,459	1,388,190	1.3%
Aleutian Islands		758	398	1,156	65.6%
Bogoslof		12	1,031	1,042	1.1%
NW	**2002**	1,439	319,025	320,463	0.4%
SE		19,226	1,140,504	1,159,730	1.7%
2002 Total		21,434	1,460,959	1,482,393	1.4%

Table 1.3. Eastern Bering Sea walleye pollock catch at age estimates based on observer data, 1979-2003. Units are in millions of fish.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Total
1979	101.4	543.2	720.0	420.2	392.6	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3.0	0.5	2,567
1980	9.8	462.4	823.3	443.5	252.2	211.0	83.7	37.6	21.8	23.9	25.5	15.9	7.7	2.5	2,421
1981	0.6	72.2	1,012.9	638.0	227.0	102.9	51.7	29.6	16.1	9.4	7.5	4.6	1.5	0.6	2,175
1982	4.8	25.3	161.4	1,172.4	422.4	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	0.7	2,004
1983	5.1	118.6	157.8	313.0	817.0	218.3	41.4	24.7	19.8	11.1	7.6	4.9	3.5	1.7	1,745
1984	2.1	45.8	88.6	430.8	491.9	654.3	133.9	35.6	25.1	15.7	7.1	2.5	2.9	1.7	1,938
1985	2.7	55.3	382.2	122.1	366.7	322.3	444.3	112.8	36.7	25.9	24.9	10.7	9.4	4.0	1,920
1986	3.1	86.0	92.3	748.5	214.1	378.1	221.9	214.2	59.7	15.2	3.3	2.6	0.3	1.2	2,040
1987	0.0	19.9	112.2	78.0	415.8	139.6	123.2	91.2	248.6	54.4	38.9	21.6	29.1	6.1	1,379
1988	0.0	10.7	455.2	422.8	252.8	545.9	225.4	105.2	39.3	97.1	18.3	10.2	3.8	5.5	2,192
1989	0.0	4.8	55.3	149.5	452.6	167.3	574.1	96.6	104.1	32.5	129.5	10.9	4.0	2.6	1,784
1990	1.0	33.2	57.3	220.7	201.8	480.3	129.9	370.4	66.1	102.5	9.1	60.4	8.5	4.7	1,746
1991	1.0	60.9	40.7	85.4	141.5	156.9	396.4	51.6	217.1	22.1	114.7	15.2	74.4	18.7	1,397
1992	0.0	79.0	721.7	143.5	98.1	125.0	145.4	276.8	109.3	165.4	59.4	50.2	14.2	91.0	2,079
1993	0.1	9.2	275.0	1,144.5	103.0	64.3	62.2	53.5	84.9	21.8	34.5	12.6	13.1	26.5	1,905
1994	0.3	31.5	59.8	383.4	1,109.5	180.5	54.9	21.0	13.5	20.1	9.1	10.7	7.6	15.7	1,918
1995	0.0	0.3	75.3	146.6	398.4	764.7	131.8	34.9	10.9	6.0	15.3	4.4	7.1	11.3	1,607
1996	0.0	9.5	19.8	44.0	145.9	353.3	493.7	192.9	35.3	16.3	10.1	9.7	4.4	14.3	1,349
1997	0.1	65.4	33.2	107.1	470.6	290.8	255.9	198.9	62.9	14.2	6.5	5.1	3.1	14.8	1,529
1998	0.0	36.3	86.7	72.3	160.8	704.0	203.6	128.6	107.6	29.1	5.7	6.3	3.0	7.4	1,552
1999	0.1	7.5	296.5	219.5	105.0	154.8	475.9	131.4	57.3	33.1	3.9	2.1	0.4	2.5	1,490
2000	0.0	15.7	82.1	427.2	345.8	106.2	168.5	353.3	86.8	29.1	22.8	5.7	1.5	1.5	1,646
2001	0.0	2.6	46.1	149.3	592.6	409.8	142.3	129.8	154.7	55.2	33.6	15.8	5.6	4.9	1,742
2002	0.6	46.9	106.1	211.2	283.5	609.8	270.7	101.2	81.8	91.0	33.8	14.4	11.9	4.3	1,867
2003	0.0	12.2	414.5	317.3	361.1	321.8	337.7	156.0	50.7	39.8	38.5	24.5	8.6	7.1	2,090
Average	5.3	74.2	255.0	344.4	352.9	311.2	210.4	120.4	70.7	38.7	27.3	13.3	9.2	10.1	1,863
Median	0.1	33.2	106.1	220.7	345.8	218.3	145.4	101.2	57.3	25.9	17.6	10.2	4.4	4.7	1,886

Table 1.4. Numbers of fishery samples used for lengths (measured) and age determinations (aged) by sex and strata, 1991-2003, of pollock as sampled by the NMFS observer program.

Length samples	Strata	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Measured	Aleutians	34,023	33,585	33,052	28,465	21,993	12,336	10,477	6,906	75	70	51	46	209
males	Northwest	126,023	110,487	38,524	28,169	17,909	22,290	58,307	32,185	16,629	43,897	58,561	42,424	70,711
	SE A Season	198,835	150,554	122,436	138,338	127,876	148,706	123,385	134,743	35,702	62,300	52,948	68,346	85,634
	SE B Season	102,225	134,371	143,420	153,336	175,524	193,832	114,826	205,309	38,208	62,855	65,921	63,702	45,342
Male subtotal		461,106	428,997	337,432	348,308	343,302	377,164	306,995	351,326	92,613	169,122	177,481	174,518	201,896
Measured	Aleutians	14,620	19,079	21,055	16,125	16,475	8,792	9,056	5,368	60	114	102	61	332
Females	Northwest	124,934	114,778	39,985	28,185	19,282	22,144	51,358	39,576	19,019	42,162	63,414	44,798	74,369
	SE A Season	184,351	142,016	112,602	146,918	124,000	140,868	102,530	108,645	31,791	55,800	50,552	66,129	90,075
	SE B Season	90,056	136,626	135,661	146,540	150,632	149,583	105,999	174,729	35,019	40,233	58,447	62,075	48,284
Female subtotal		413,961	412,499	309,303	337,768	310,389	321,387	268,943	295,104	85,889	138,309	172,515	173,063	213,060
Total measured pollock		875,067	841,496	646,735	686,076	653,691	698,551	575,938	646,430	178,502	307,431	349,996	347,581	414,956
Age samples	Strata	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Aged	Aleutians	22	110	81	157	73	86	15	142	0	0	0	0	1
males	Northwest	320	179	147	132	123	0	326	216	312	269	257	237	379
	SE A Season	373	454	451	200	297	470	431	588	533	660	695	646	674
	SE B Season	248	317	475	571	415	442	284	307	728	833	544	797	594
Male subtotal		963	1,060	1,154	1,060	908	998	1,056	1,098	1,573	1,762	1,496	1,680	1,648
Aged	Aleutians	23	121	82	151	105	77	15	166	0	0	1	0	0
females	Northwest	340	178	153	142	131	0	326	236	312	313	306	281	400
	SE A Season	385	458	478	201	313	451	434	652	485	616	678	677	735
	SE B Season	233	332	458	574	392	434	312	308	725	574	465	839	623
Female subtotal		981	1,089	1,171	1,068	941	962	1,087	1,192	1,522	1,504	1,450	1,797	1,758
Total aged pollock		1,944	2,149	2,325	2,128	1,849	1,960	2,143	2,290	3,095	3,266	2,946	3,477	3,406

Table 1.5. Sampling effort of pollock in the EBS based on the NMFS bottom trawl survey 1982-2003.

Year	**Number of Hauls**	**Lengths**	**Aged**	**Year**	**Number of Hauls**	**Lengths**	**Aged**
1982	329	40,001	1,611	1993	355	43,278	1,385
1983	354	78,033	1,931	1994	355	38,901	1,141
1984	355	40,530	1,806	1995	356	25,673	1,156
1985	353	48,642	1,913	1996	355	40,789	1,387
1986	354	41,101	1,344	1997	356	35,536	1,193
1987	342	40,144	1,607	1998	355	37,673	1,261
1988	353	40,408	1,173	1999	353	32,532	1,385
1989	353	38,926	1,227	2000	352	41,762	1,545
1990	352	34,814	1,257	2001	355	47,335	1,641
1991	351	43,406	1,083	2002	355	43,361	1,695
1992	336	34,024	1,263	2003	356	46,480	1,638
				2004	376	44,102	1,660

Table 1.6. Biomass (age 1+) of eastern Bering Sea walleye pollock as estimated by surveys 1979-2004 (millions of tons).

Year	Bottom trawl Survey (t)	EIT Survey (t)	EIT Percent age 3+	Total[4] (t)	Near bottom biomass
1979	3.20	7.46	(22%)	10.66	30%
1980	1.00				
1981	2.30				
1982	2.86	4.90	(95%)	7.76	46%
1983	6.24				
1984	4.89				
1985	4.63	4.80	(97%)	9.43	54%
1986	4.90				
1987	5.11				
1988	7.11	4.68	(97%)	11.79	63%
1989	5.93				
1990	7.13				
1991	5.11	1.45	(46%)	6.56	79%
1992	4.37				
1993	5.52				
1994	4.98	2.89	(85%)	7.87	64%
1995	5.41				
1996	3.20	2.31	(97%)	5.51	60%
1997	3.03	2.59	(70%)	5.62	54%
1998	2.21				
1999	3.57	3.29[5]	(95%)	6.86	52%
2000	5.14	3.05	(95%)	8.19	63%
2001	4.14				
2002	4.77	3.60	(84%)	8.42	57%
2003	8.14				
2004	3.75	3.31	(95%)	7.23	52%

[4] Although the two survey estimates are added in this table, the stock assessment model treats them as separate, independent indices (survey "*q*'s" are estimated).

[5] This figure excludes the zone near the "horseshoe" area of the EBS (southeast) not usually surveyed, the value including this area was 3.35 million tons.

Table 1.7. Number of hauls and sample sizes for EBS pollock collected by the EIT surveys.

Year	Stratum	No. Hauls	No. lengths	No. otoliths collected	No. aged
1979	**Total**	25	7,722	NA	2,610
1982	**Total**	48	8,687	NA	2,741
	Midwater, east of St Paul	13	1,725		783
	Midwater, west of St Paul	31	6,689		1,958
	Bottom	4	273		0
1985	**Total** (Legs1 &2)	73	19,872	NA	2,739
1988	**Total**	25	6,619	1,519	1,471
1991	**Total**	62	16,343	2,065	1,663
1994	**Total**	77	21,506	4,973	1,770
	East of 170 W				612
	West of 170 W				1,158
1996	**Total**	57	16,910	1,950	1,926
	East of 170 W				815
	West of 170 W				1,111
1997	**Total**	86	30,535	3,635	2,285
	East of 170 W				936
	West of 170 W				1,349
1999	**Total**	122	42,364	4,946	2,446
	East of 170 W	45	13,842	1,945	946
	West of 170 W	77	28,522	3,001	1,500
2000	**Total**	128	43,729	3,459	2,253
	East of 170 W	32	7,721	850	850
	West of 170 W	96	36,008	2,609	1,403
2002	**Total**	126	40,234	3,233	2,200
	East of 170 W	48	14,601	1,424	1,000
	West of 170 W	78	25,633	1,809	1,200
2004	**Total (US zone)**	139	29,934	3,251	-
	East of 170 W	45	8,881	1,152	-
	West of 170 W	94	21,053	2,099	-
	Russian zone	15	5,893	461	

Table 1.8. Distribution of pollock between areas from summer echo integration-trawl surveys on the Bering Sea shelf, 1994-2004. Data are estimated pollock biomass from near-surface down to 3 m off bottom.

	Dates	Area (nmi)^2	SCA	Biomass (million mt) (percent) E170-SCA	W170	Total Biomass (million mt)
1994	Jul 9-Aug 19	78,251	0.312	0.399	2.18	2.89
			(11%)	(14%)	(75%)	
1996	Jul 20-Aug 30	93,810	0.215	0.269	1.83	2.31
			(9%)	(12%)	(79%)	
1997	Jul 17-Sept 4	102,770	0.246	0.527	1.82	2.59
			(10%)	(20%)	(70%)	
1999	Jun 7-Aug 5	103,670	0.299	0.579	2.41	3.29
			(9%)	(18%)	(73%)	
2000	Jun 7- Aug 2	106,140	0.393	0.498	2.16	3.05
			(13%)	(16%)	(71%)	
2002	Jun 4 – Jul 30	99,526	0.647	0.797	2.178	3.622
			(18%)	(22%)	(60%)	
2004	Jun 4 – Jul 29	99,659	0.498	0.516	2.293	3.307
			(15%)	(16%)	(69%)	

Key: SCA = Sea lion Conservation Area
E170 - SCA = East of 170 W minus SCA
W170 = West of 170 W

Table 1.9. Fishery annual average weights-at-age (kg) as estimated from NMFS observer data. These values are used in the model for computing the predicted fishery catch (in weight) and for computing biomass levels for EBS pollock. NOTE: 2004 weight-at-age is treated as the three-year average of values from 2001-2003.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1964-1990	0.007	0.170	0.303	0.447	0.589	0.722	0.840	0.942	1.029	1.102	1.163	1.212	1.253	1.286	1.312
1991	0.007	0.170	0.277	0.471	0.603	0.722	0.837	0.877	0.996	1.109	1.127	1.194	1.207	1.256	1.244
1992	0.007	0.170	0.387	0.454	0.615	0.660	0.745	0.898	0.960	1.151	1.174	1.203	1.132	1.184	1.304
1993	0.007	0.170	0.492	0.611	0.657	0.770	0.934	1.078	1.187	1.238	1.385	1.512	1.632	1.587	1.465
1994	0.007	0.170	0.398	0.628	0.716	0.731	0.709	0.995	1.287	1.228	1.197	1.329	1.308	1.282	1.282
1995	0.007	0.170	0.389	0.505	0.733	0.841	0.854	1.000	1.235	1.314	1.375	1.488	1.402	1.336	1.491
1996	0.007	0.170	0.332	0.448	0.717	0.817	0.964	0.966	1.059	1.142	1.371	1.452	1.487	1.679	1.460
1997	0.007	0.170	0.325	0.468	0.554	0.745	0.890	1.071	1.084	1.236	1.332	1.421	1.570	1.451	1.418
1998	0.007	0.170	0.362	0.574	0.629	0.636	0.778	1.046	1.173	1.242	1.236	1.337	1.443	1.487	1.709
1999	0.007	0.170	0.412	0.492	0.655	0.697	0.750	0.960	1.081	1.347	1.275	1.516	2.399	1.118	1.104
2000	0.007	0.170	0.380	0.501	0.626	0.779	0.773	0.822	1.020	1.046	1.311	1.387	1.504	1.492	1.552
2001	0.007	0.170	0.275	0.512	0.678	0.818	0.990	1.055	1.073	1.195	1.279	1.376	1.482	1.506	1.597
2002	0.007	0.170	0.389	0.462	0.673	0.829	0.944	1.089	1.111	1.137	1.312	1.389	1.495	1.512	1.559
2003	0.007	0.170	0.489	0.537	0.636	0.739	0.878	1.011	1.157	1.244	1.284	1.384	1.494	1.504	1.569
2004	0.007	0.170	0.384	0.503	0.662	0.795	0.937	1.052	1.114	1.192	1.292	1.383	1.490	1.507	1.575

Table 1.10. Pollock "sample sizes" assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and EIT surveys, 1964-2004. Note that for the EIT in 2004, since the BTS age-length key was used, the sample size was set to half of the number of trawls.

Year	Fishery		Year	Fishery	BTS	EIT
1964	10		1979	50		25
1965	10		1980	50		
1966	10		1981	50		
1967	10		1982	50	100	48
1968	10		1983	50	100	
1969	10		1984	50	100	
1970	10		1985	50	100	73
1971	10		1986	50	100	
1972	10		1987	50	100	
1973	10		1988	50	100	25
1974	10		1989	50	100	
1975	10		1990	50	100	
1976	10		1991	200	100	62
1977	10		1992	200	100	
1978	50		1993	200	100	
			1994	200	100	77
			1995	200	100	
			1996	200	100	57
			1997	200	100	86
			1998	200	100	
			1999	200	100	122
			2000	200	100	128
			2001	200	100	
			2002	200	100	126
			2003	200	100	
			2004	200	100	69.5

Table 1.11. Results comparing fits Models 1-6. See text for additional model descriptions.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
-ln(Likelihoods)						
Priors	9.10	9.13	8.61	9.09	8.96	8.87
CPUE	1.95	2.05	0.49	1.96	1.84	1.78
Bottom Trawl Survey	9.32	8.84	9.08	9.35	11.06	10.69
EIT Survey	-5.74	-7.80	-5.27	-5.75	-5.36	-5.48
Fishery Age Comp	-817.43	-823.30	-913.55	-817.39	-819.10	-818.83
Bottom Trawl Age Comp	-372.39	-367.28	-385.23	-372.52	-372.27	-371.95
EIT Age Comp	-252.24	-260.08	-251.16	-252.25	-252.19	-252.21
Stock-recruitment curve	2.74	5.34	1.66	2.75	2.78	2.70
Recruitment deviations	18.37	23.32	14.17	18.37	18.45	18.61
Catch	0.00	0.00	0.00	0.00	0.00	0.00
Fishery selectivity penalty/prior	36.01	38.10	40.60	35.99	37.66	37.48
BTS penalty/prior	15.08	13.27	15.32	15.14	15.04	15.08
EIT penalty/prior	24.06	26.02	25.74	24.06	24.21	24.18
Total –ln(likelihood)	-1331.17	-1332.39	-1439.54	-1331.19	-1328.92	-1329.08
Number of parameters	624	624	910	625	623	624
Age Composition data						
Effective N Fishery	175	204	2,461	174	171	172
Effective N Bottom trawl survey	144	150	408	146	156	148
Effective N Hydro acoustic survey	156	174	156	156	155	157

Survey abundance estimates, RMSE*	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Trawl Survey	0.229	0.226	0.228	0.231	0.253	0.248
EIT survey	0.337	0.303	0.344	0.337	0.343	0.341

Recruitment Residuals	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Due to Stock	0.25	0.22	0.25	0.25	0.24	0.24
Residual RMSE	0.38	0.51	0.31	0.38	0.38	0.39
Total	0.62	0.72	0.57	0.62	0.63	0.63

Notes: Effective N (sample size) computations are as presented in McAllister and Ianelli (1997).

RMSE = $\sqrt{\frac{\sum \ln\left(obs/pred\right)^2}{n}}$

Table 1.12. Results reflecting the stock condition for Models 1-6. Biomass units are thousands of tons, recruitment in millions of fish. Values in parentheses are coefficients of variation (CV's) of values immediately above. See text for model descriptions. (HPD=Highest posterior density)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Biomass						
Year 2005 spawning biomass[6]	2,706	2,584	3,187	2,686	3,265	3,307
Year 2005 spawning biomass[7]	2,871	2,745	3,317	2,849	3,436	3,489
(CV)	(19%)	(19%)	(20%)	(20%)	(16%)	(17%)
2004 spawning biomass	3,223	3,125	3,760	3,201	3,841	3,945
B_{msy}	2,226	2,033	2,597	2,222	2,448	2,481
(CV)	(27%)	(24%)	(30%)	(27%)	(26%)	(25%)
$B_{40\%}$	2,645	2,607	2,775	2,640	2,849	2,843
(CV)	(5%)	(5%)	(5%)	(5%)	(4%)	(4%)
$B_{35\%}$	2,314	2,281	2,428	2,310	2,493	2,488
B0 (stock-recruitment curve)	5,671	5,195	6,478	5,660	6,224	6,295
Percent of Bmsy spawning biomass	122%	127%	123%	121%	133%	133%
Percent of $B_{40\%}$% spawning biomass	109%	105%	120%	108%	121%	123%
2005 age 3+ biomass (point estimate)	8,573	8,131	9,729	8,514	10,103	10,425
Ratio B2005/B2004 (3+ biomass)	87%	85%	87%	87%	88%	87%
Recruitment						
Steepness parameter (h)	0.646	0.648	0.619	0.646	0.639	0.634
Avg Recruitment (all yrs)	22,444	22,147	23,842	22,414	23,857	25,493
(CV)	62%	73%	58%	62%	63%	63%
Avg. Recruitment (since 1978)	24,597	24,281	25,802	24,552	26,500	28,579
(CV since 1978)	65%	78%	61%	65%	65%	65%
1996 year class	31,163	34,180	31,926	31,011	34,355	36,705
(CV 1996 year class)	(8%)	(8%)	(9%)	(9%)	(7%)	(14%)
Natural Mortality						
(age 3 and older)	0.300	0.300	0.300	0.300	0.300	0.315

[6] At time of spawning, fishing at F_{msy}

[7] At time of spawning, fishing at $F_{40\%}$

Table 1.13. Results relating to yield for Models 1-6. Biomass units are thousands of tons, recruitment in millions of fish. See text for model descriptions.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Yield projections						
B_{msy} (age 3+; GM)	8,397	7,719	9,378	8,381	9,153	9,490
2005 Age 3+ biomass (GM)	8,410	7,978	9,527	8,347	9,957	10,256
MSYR (HM)	0.233	0.235	0.214	0.233	0.228	0.231
2005 MSYR yield (Tier 1 ABC)	**1,962**	1,874	2,043	1,947	2,274	2,370
MSYR (AM)	0.250	0.251	0.232	0.250	0.245	0.248
2005 MSYR OFL	**2,104**	2,005	2,209	2,087	2,444	2,549
2005 F_{msy} yield (HM)	1,856	1,816	1,839	1,834	2,180	2,250
2005 Yield F_{msy} (AM)	2,900	2,796	2,994	2,878	3,301	3,545
	(45%)	(44%)	(47%)	(45%)	(44%)	(46%)
MSY (long-term expectation)	2,065	1,902	2,146	2,061	2,203	2,314
Average F's						
F_{msy}	0.475	0.474	0.386	0.475	0.421	0.457
	(111%)	(108%)	(111%)	(111%)	(106%)	(113%)
$F_{40\%}$ (average F)	0.277	0.275	0.263	0.277	0.259	0.285
$F_{35\%}$ 2005 Yield	2,325	2,227	2,706	2,308	2,737	2,993
2005 yield F40%	1,897	1,821	2,205	1,883	2,245	2,449
Full Selection F's						
F_{msy} (AM)	0.892	0.906	0.845	0.893	0.830	0.888
F_{msy} (HM)	0.402	0.409	0.330	0.408	0.366	0.390
F40%	0.520	0.526	0.575	0.521	0.511	0.555
$F_{35\%}$	0.668	0.673	0.741	0.669	0.651	0.712
Spawning biomass levels						
$B_{40\%}$	2,645	2,607	2,775	2,640	2,849	2,843
$B_{35\%}$	2,314	2,281	2,428	2,310	2,493	2,488
B_0 (stock-recruitment curve)	5,671	5,195	6,478	5,660	6,224	6,295

Notes: MSYR = exploitation rate relative to begin-year age 3+ biomass corresponding to F_{msy}.
F_{msy} yields calculated within the model (i.e., including uncertainty in both the estimate of F_{msy} and in projected stock size).
HM = Harmonic mean
GM = Geometric mean
AM = Arithmetic mean

Table 1.14 Estimates of numbers at age for the EBS pollock stock under Model 1 (millions).

	1	2	3	4	5	6	7	8	9	10+	Total
1964	4,987	3,939	2,248	542	232	360	147	61	33	208	12,758
1965	20,730	2,023	2,481	1,573	333	141	224	94	40	162	27,803
1966	14,644	8,412	1,275	1,739	974	204	88	144	62	136	27,678
1967	28,171	5,942	5,278	878	1,100	621	133	58	96	133	42,410
1968	25,929	11,413	3,680	3,433	491	623	366	80	36	142	46,191
1969	26,790	10,505	7,074	2,401	1,931	280	369	221	49	112	49,731
1970	21,300	10,835	6,448	4,440	1,422	1,150	170	224	134	95	46,218
1971	9,879	8,604	6,589	3,886	2,489	803	666	98	129	129	33,273
1972	11,315	3,981	5,148	3,700	1,980	1,281	427	354	52	134	28,372
1973	27,627	4,561	2,278	2,660	1,751	955	634	215	179	96	40,955
1974	21,201	11,107	2,527	1,057	1,102	743	420	284	97	126	38,664
1975	17,674	8,503	5,970	1,060	386	415	292	168	116	93	34,678
1976	13,383	7,132	4,935	2,681	411	155	175	126	74	93	29,166
1977	14,623	5,409	4,218	2,448	1,182	187	73	84	62	83	28,368
1978	28,255	5,917	3,247	2,268	1,198	593	96	38	45	78	41,735
1979	64,059	11,455	3,601	1,844	1,115	556	280	46	18	60	83,034
1980	26,341	25,975	6,992	2,080	931	533	270	138	23	39	63,322
1981	30,002	10,688	16,021	4,286	1,151	494	287	147	75	34	63,183
1982	16,045	12,186	6,745	11,083	2,587	617	256	151	78	59	49,808
1983	53,056	6,520	7,722	4,797	7,267	1,581	369	155	92	84	81,642
1984	12,594	21,561	4,137	5,542	3,232	4,635	992	234	98	112	53,136
1985	34,351	5,118	13,688	2,978	3,792	2,084	2,864	606	146	129	65,756
1986	12,624	13,960	3,249	9,856	2,039	2,449	1,290	1,753	378	168	47,767
1987	7,375	5,130	8,864	2,342	6,770	1,324	1,527	796	1,101	339	35,569
1988	4,405	2,998	3,260	6,417	1,628	4,539	859	953	498	908	26,465
1989	9,264	1,790	1,904	2,349	4,403	1,069	2,863	517	576	859	25,593
1990	52,952	3,765	1,137	1,369	1,603	2,867	667	1,699	308	865	67,230
1991	25,508	21,522	2,390	811	920	962	1,635	353	924	643	55,666
1992	20,161	10,367	13,662	1,704	545	552	549	866	192	851	49,448
1993	51,313	8,193	6,566	9,559	1,091	294	276	246	403	494	78,436
1994	13,342	20,857	5,212	4,779	6,208	597	133	136	130	507	51,901
1995	10,007	5,423	13,277	3,813	3,224	3,707	312	74	79	391	40,307
1996	22,444	4,068	3,454	9,744	2,635	2,036	2,121	186	46	304	47,038
1997	31,163	9,123	2,588	2,525	6,920	1,796	1,231	1,166	105	208	56,827
1998	14,419	12,668	5,804	1,893	1,797	4,732	1,095	686	668	187	43,949
1999	16,444	5,861	8,061	4,252	1,353	1,239	2,944	628	403	511	41,695
2000	22,552	6,685	3,732	5,886	2,955	883	772	1,759	376	578	46,178
2001	38,232	9,167	4,255	2,717	4,040	1,882	532	442	1,010	588	62,864
2002	11,509	15,541	5,834	3,094	1,854	2,544	1,117	299	249	963	43,003
2003	11,106	4,678	9,875	4,196	2,116	1,144	1,363	602	164	729	35,972
2004	13,532	4,514	2,970	7,061	2,824	1,258	574	690	310	522	34,256
Median	20,161	8,193	4,935	2,717	1,751	955	427	224	116	162	43,949
Mean	22,227	8,978	5,571	3,701	2,243	1,339	767	429	235	316	45,806

Table 1.15. Estimated catch-at-age of EBS pollock for Model 1 (millions).

	1	2	3	4	5	6	7	8	9	10+	Total
1964	6	39	107	79	36	50	18	6	3	16	361
1965	26	20	115	224	50	19	26	9	4	12	506
1966	19	109	78	220	118	21	8	13	5	11	603
1967	66	137	558	188	226	111	22	9	14	18	1,348
1968	60	257	381	718	99	109	59	12	5	19	1,717
1969	92	316	938	419	329	44	58	35	8	21	2,258
1970	91	404	1,044	940	294	218	32	43	26	21	3,114
1971	57	428	1,388	1,058	663	197	165	24	32	36	4,046
1972	64	330	1,358	1,169	604	370	120	97	14	35	4,161
1973	203	484	744	1,029	655	340	220	73	60	31	3,837
1974	189	1,417	961	472	476	306	169	112	38	48	4,186
1975	87	618	2,062	444	155	156	106	60	40	31	3,758
1976	53	418	1,424	951	139	49	53	37	21	26	3,172
1977	46	256	1,007	726	334	49	18	21	15	19	2,491
1978	53	219	661	666	392	187	30	12	13	23	2,255
1979	113	396	693	513	345	166	82	13	5	16	2,343
1980	35	685	1,050	460	230	127	62	31	5	8	2,695
1981	20	88	919	691	277	129	71	35	18	8	2,256
1982	6	60	234	1,105	394	103	40	23	12	9	1,986
1983	16	25	209	377	877	210	47	19	11	10	1,800
1984	4	75	101	366	363	667	151	32	14	17	1,792
1985	10	18	332	195	421	298	433	83	21	20	1,830
1986	4	46	76	620	218	337	188	231	52	25	1,797
1987	2	14	175	125	557	143	209	107	143	43	1,517
1988	1	10	78	410	161	585	140	152	77	137	1,750
1989	2	6	48	160	462	146	495	88	95	137	1,640
1990	11	14	37	110	265	574	166	394	74	192	1,835
1991	5	78	77	65	152	192	406	82	221	143	1,422
1992	6	56	656	201	129	156	190	281	64	264	2,003
1993	8	16	100	1,022	248	100	81	62	90	95	1,821
1994	2	28	56	370	1,046	153	29	25	21	73	1,804
1995	1	5	107	221	413	734	53	11	10	42	1,596
1996	3	8	39	349	183	324	476	38	9	50	1,479
1997	4	16	28	87	461	275	266	230	20	33	1,420
1998	2	20	56	58	108	657	216	123	116	27	1,384
1999	2	7	100	228	139	171	495	105	55	61	1,361
2000	3	10	55	375	360	143	152	344	60	80	1,582
2001	5	14	68	185	525	326	112	92	172	86	1,585
2002	2	44	147	206	269	614	264	68	49	149	1,812
2003	3	16	298	332	362	322	376	160	38	125	2,031
2004	3	16	91	571	493	360	161	187	74	91	2,047
Median	8	46	175	375	329	187	120	60	21	31	1,812
Mean	34	176	455	456	342	250	158	87	44	56	2,059

Table 1.16. Point estimates for EBS pollock Model 1 age 3+ biomass and female spawning biomass (thousands of tons), and age 1 recruitment for 1964-2004 (millions).

Year	Age 3+	Spawning	Age 1 Rec.	Year	Age 3+	Spawning	Age 1 Rec.
1964	1,789	523	4,987	1985	12,492	3,769	34,351
1965	2,272	642	20,730	1986	11,677	4,003	12,624
1966	2,326	748	14,644	1987	12,226	4,095	7,375
1967	3,514	917	28,171	1988	11,243	4,001	4,405
1968	3,976	1,112	25,929	1989	9,466	3,568	9,264
1969	5,258	1,383	26,790	1990	7,454	2,839	52,952
1970	6,211	1,692	21,300	1991	5,637	2,073	25,508
1971	6,714	1,853	9,879	1992	9,120	2,139	20,161
1972	6,204	1,757	11,315	1993	11,721	3,177	51,313
1973	4,632	1,400	27,627	1994	10,998	3,425	13,342
1974	3,288	951	21,201	1995	13,554	3,793	10,007
1975	3,440	771	17,674	1996	11,772	3,944	22,444
1976	3,497	806	13,383	1997	9,949	3,616	31,163
1977	3,504	878	14,623	1998	9,943	3,350	14,419
1978	3,385	907	28,255	1999	11,093	3,409	16,444
1979	3,341	896	64,059	2000	10,036	3,352	22,552
1980	4,409	1,065	26,341	2001	9,675	3,411	38,232
1981	8,301	1,771	30,002	2002	9,899	3,211	11,509
1982	9,472	2,666	16,045	2003	12,239	3,348	11,106
1983	10,552	3,283	53,056	2004	9,894	2,929	13,532
1984	10,263	3,500	12,594	2005	8,573	2,454	

Table 1.17. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for Model 1 (current assessment) compared to estimates from the 2003-1997 assessments for EBS pollock. NOTE: see Ianelli et al. (2001) for a discussion on the interpretation of age-3+ biomass estimates.

	Current		**2003**		**2002**		**2001**		**2000**		**1999**		**1998**		**1997**	
	Assess.	**CV**	**Assess.**	**CV**	**Assess.**	**CV**	**Assess.**	**CV**	**Assess.**	**CV**	**Assess.**	**CV**	**Assess.**	**CV**	**Assess.**	**CV**
1964	1,789	45%	1,822	46%	1,784	46%	1,726	46%	751	35%	917	41%	1,037	30%		
1965	2,272	40%	2,312	40%	2,266	40%	2,196	40%	976	36%	976	32%	1,227	26%		
1966	2,326	40%	2,372	40%	2,324	40%	2,251	41%	1,001	39%	919	31%	1,096	28%		
1967	3,514	33%	3,575	33%	3,511	33%	3,420	33%	1,957	34%	1,858	24%	2,095	22%		
1968	3,976	34%	4,049	34%	3,976	34%	3,876	34%	2,312	36%	2,312	27%	2,510	23%		
1969	5,258	31%	5,340	31%	5,252	32%	5,137	32%	3,379	29%	3,579	22%	3,810	19%		
1970	6,211	30%	6,296	30%	6,201	30%	6,079	30%	3,998	25%	4,479	19%	5,083	15%		
1971	6,714	27%	6,797	27%	6,702	27%	6,580	28%	4,372	21%	5,161	16%	5,813	12%		
1972	6,204	26%	6,282	26%	6,194	26%	6,078	27%	3,984	19%	4,896	15%	5,648	11%		
1973	4,632	31%	4,705	31%	4,626	31%	4,520	32%	2,873	26%	3,357	20%	3,922	14%		
1974	3,288	38%	3,356	38%	3,287	38%	3,193	39%	1,648	41%	1,952	28%	2,342	19%		
1975	3,440	26%	3,489	27%	3,436	27%	3,366	26%	2,536	23%	2,683	18%	3,014	13%		
1976	3,497	22%	3,538	22%	3,492	22%	3,434	22%	2,694	17%	2,748	16%	3,008	13%		
1977	3,504	20%	3,541	20%	3,496	20%	3,444	20%	2,701	13%	2,716	14%	2,894	13%		
1978	3,385	20%	3,422	20%	3,375	20%	3,327	19%	2,608	14%	2,668	15%	2,867	13%	3,244	19%
1979	3,341	19%	3,380	19%	3,329	19%	3,280	19%	2,640	16%	2,720	16%	2,933	15%	3,183	21%
1980	4,409	16%	4,462	16%	4,385	16%	4,322	16%	3,723	15%	3,888	16%	4,294	14%	4,618	19%
1981	8,301	13%	8,414	14%	8,239	14%	8,127	14%	7,834	12%	8,064	13%	8,569	12%	9,190	16%
1982	9,472	13%	9,614	13%	9,388	13%	9,261	13%	9,021	13%	9,229	13%	9,778	12%	10,524	17%
1983	10,552	13%	10,728	13%	10,441	13%	10,298	13%	9,958	12%	10,153	12%	10,705	12%	11,555	16%
1984	10,263	13%	10,456	13%	10,143	13%	10,000	13%	9,518	13%	9,685	12%	10,179	12%	11,028	17%
1985	12,492	11%	12,771	11%	12,344	11%	12,181	11%	11,182	10%	11,370	10%	11,919	11%	12,853	15%
1986	11,677	11%	11,973	11%	11,538	11%	11,381	11%	10,277	10%	10,440	10%	10,913	11%	11,796	16%
1987	12,226	10%	12,596	10%	12,116	10%	11,951	10%	10,636	9%	10,769	9%	11,116	10%	11,952	15%
1988	11,243	10%	11,633	10%	11,317	10%	11,159	10%	9,910	8%	9,991	9%	10,274	10%	11,020	15%
1989	9,466	10%	9,850	10%	9,540	10%	9,394	10%	8,251	9%	8,305	9%	8,546	10%	9,210	16%
1990	7,454	11%	7,811	11%	7,524	11%	7,393	11%	6,473	10%	6,497	10%	6,659	12%	7,240	18%
1991	5,637	12%	5,977	13%	5,708	13%	5,582	12%	4,859	11%	4,842	11%	5,180	13%	5,690	20%
1992	9,120	10%	9,614	10%	9,227	10%	8,898	10%	7,920	9%	7,800	10%	8,294	13%	9,465	21%
1993	11,721	10%	12,363	11%	12,110	10%	11,503	10%	10,233	10%	9,873	10%	10,279	16%	12,086	25%
1994	10,998	10%	11,696	11%	11,358	11%	10,590	11%	9,285	10%	8,622	12%	8,917	18%	10,626	29%
1995	13,554	11%	14,474	12%	13,848	12%	12,617	13%	10,267	12%	8,817	15%	8,680	22%	9,998	32%
1996	11,772	12%	12,630	13%	11,988	13%	10,752	14%	8,556	14%	7,147	17%	6,811	26%	8,142	36%
1997	9,949	13%	10,775	15%	10,142	15%	8,984	16%	7,057	17%	5,710	22%	5,307	31%	6,631	42%
1998	9,943	13%	11,110	16%	10,466	17%	9,335	20%	7,448	22%	5,961	28%	5,133	39%	5,133	39%
1999	11,093	14%	13,339	20%	12,712	21%	12,593	28%	10,772	30%	7,513	36%				
2000	10,036	15%	12,498	23%	11,807	24%	11,680	33%	10,490	34%						
2001	9,675	17%	12,394	27%	11,511	27%	11,145	39%								
2002	9,899	20%	12,930	32%	11,118	33%										
2003	12,239	28%	12,688	37%												
2004	9,894	33%	11,217	42%												
2005	8,573	39%														

Table 1.18 Projections of Model 1 spawning biomass (thousands of tons) for EBS pollock for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 7,232; 2,645; and 2,314 t, respectively.

Sp.Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	3,223	3,223	3,223	3,223	3,223	3,223	3,223
2005	2,871	2,871	2,994	2,957	3,123	2,804	2,871
2006	2,298	2,298	2,722	2,575	3,292	2,107	2,298
2007	2,138	2,138	2,658	2,430	3,584	1,950	2,104
2008	2,300	2,300	2,837	2,564	3,991	2,123	2,183
2009	2,553	2,553	3,130	2,831	4,465	2,366	2,387
2010	2,726	2,726	3,387	3,060	4,931	2,507	2,515
2011	2,791	2,791	3,550	3,195	5,329	2,541	2,545
2012	2,794	2,794	3,631	3,253	5,639	2,526	2,528
2013	2,792	2,792	3,679	3,285	5,887	2,518	2,519
2014	2,804	2,804	3,723	3,319	6,089	2,529	2,530
2015	2,829	2,829	3,770	3,359	6,269	2,553	2,553
2016	2,836	2,836	3,794	3,378	6,401	2,556	2,556
2017	2,824	2,824	3,798	3,376	6,497	2,542	2,542
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	0.212	0.212	0.212	0.212	0.212	0.212	0.212
2005	0.277	0.277	0.139	0.179	0.000	0.356	0.277
2006	0.235	0.235	0.134	0.179	0.000	0.275	0.235
2007	0.216	0.216	0.129	0.179	0.000	0.252	0.273
2008	0.226	0.226	0.129	0.179	0.000	0.269	0.276
2009	0.238	0.238	0.131	0.179	0.000	0.289	0.292
2010	0.247	0.247	0.134	0.179	0.000	0.301	0.302
2011	0.250	0.250	0.135	0.179	0.000	0.305	0.305
2012	0.251	0.251	0.135	0.179	0.000	0.305	0.305
2013	0.252	0.252	0.135	0.179	0.000	0.305	0.305
2014	0.252	0.252	0.136	0.179	0.000	0.305	0.305
2015	0.252	0.252	0.136	0.179	0.000	0.306	0.306
2016	0.252	0.252	0.136	0.179	0.000	0.306	0.306
2017	0.252	0.252	0.136	0.179	0.000	0.306	0.306
Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	1,492	1,492	1,492	1,492	1,492	1,492	1,492
2005	1,897	1,897	1,032	1,300	0	2,324	1,897
2006	1,415	1,415	1,010	1,250	0	1,481	1,415
2007	1,086	1,086	864	1,060	0	1,117	1,324
2008	1,109	1,109	845	1,009	0	1,184	1,256
2009	1,298	1,298	930	1,095	0	1,426	1,448
2010	1,507	1,507	1,072	1,247	0	1,646	1,652
2011	1,604	1,604	1,168	1,346	0	1,726	1,727
2012	1,635	1,635	1,224	1,399	0	1,738	1,739
2013	1,630	1,630	1,243	1,412	0	1,720	1,720
2014	1,625	1,625	1,250	1,415	0	1,715	1,715
2015	1,638	1,638	1,262	1,427	0	1,734	1,734
2016	1,649	1,649	1,272	1,439	0	1,743	1,743
2017	1,651	1,651	1,278	1,445	0	1,744	1,744

Table 1.19. Analysis of ecosystem considerations for BSAI pollock and the pollock fishery.

Indicator	Observation	Interpretation	Evaluation
Ecosystem effects on EBS pollock			
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys, changes mean wt-at-age	Stable, data limited	Probably no concern
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on pollock	Probably no concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Probably no concern
Fish (Pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to pollock mortality	
Changes in habitat quality			
Temperature regime	Cold years pollock distribution towards NW on average	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability low	No concern
Fishery effects on ecosystem			
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Likely to be safe	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Likely to be safe	No concern
HAPC biota	Likely minor impact	Likely to be safe	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Generally more diffuse	Mixed potential impact (fur seals vs Steller sea lions)	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Probably no concern
Fishery contribution to discards and offal production	Decreasing	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	New study initiated in 2002	NA	Possible concern

Table 1.20 Bycatch estimates (mt) of target species caught in the BSAI directed pollock fishery, 1997-2002 based on then NMFS Blend data.

	1997	1998	1999	2000	2001	2002
Pacific Cod	8,478	6,560	3,220	3,432	3,879	5,928
Flathead Sole	2,353	2,118	1,885	2,510	2,199	1,844
Rock Sole	1,529	779	1,058	2,688	1,673	1,885
Yellowfin Sole	606	1,762	350	1,466	594	768
Arrowtooth Flounder	1,155	1,762	273	979	529	607
Pacific Ocean Perch	512	692	121	22	574	545
Atka Mackerel	229	91	165	2	41	221
Rex Sole	151	68	34	10	103	169
Greenland Turbot	125	178	30	52	68	70
Alaska Plaice	1	14	3	147	14	50
All other	93	41	31	77	118	103

Table 1.21 Bycatch estimates (mt) of non-target species caught in the BSAI directed pollock fishery, 1997-2002 based on observer data.

Data	1997	1998	1999	2000	2001	2002
Jellyfish	6,632	6,129	6,176	9,361	3,095	1,530
Squid	1,538	1,236	475	379	1,776	1,708
Skates	350	406	376	598	628	870
Otherfish (non specified)	222	139	156	236	156	134
Sculpins	109	188	67	185	199	199
Sleeper shark	105	74	77	104	206	149
Smelts	20	30	39	49	72	15
Grenadiers	36	41	79	33	12	6
Salmon shark	7	16	25	20	22	27
Starfish	7	58	7	6	13	17
Shark	16	45	10	0	2	2
Benthic invertebrates	3	26	7	2	1	2
Sponges	1	21	2	0	2	0
Octopus	1	5	0	1	5	8
Crabs	1	8	1	1	2	1
Anemone	3	2	0	6	0	1
Tunicate	0	2	1	0	4	4
Unidentified invertebrates	0	3	0	4	0	0
Seapen/whip	0	0	0	1	1	2
Lanternfish	0	0	0	0	0	3
Birds	0	2	1	0	0	0
Echinoderms	1	3	0	0	0	0
Sandfish	0	0	0	0	0	0
Shrimp	0	0	0	0	0	0
Sticheidae	0	0	0	0	0	0
Coral	0	0	0	0	0	0
Dogfish		0	0	0	0	0
Sandlance	0			0		0

Table 1.22. Summary results for Model 1, EBS pollock. Tonnage units are thousands of metric tons.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop. F. Mature	0.000	0.004	0.145	0.321	0.421	0.451	0.474	0.482	0.485	0.500	0.500	0.500	0.500	0.500	0.500
Fish. Selectivity	0.002	0.015	0.109	0.426	0.896	1.375	1.694	1.750	1.500	1.258	1.195	1.195	1.195	1.195	1.195

Base model	**Model 1**
Tier	1
Age 3+ 2005 begin-year biomass	**8,573** t
2004 Spawning biomass	**3,223** t
B_{msy}	**2,226** t
$B_{40\%}$	**2,645** t
$B_{35\%}$	**2,314** t
$B_{100\%}$	**7,232** t
B_0	**5,671** t
Yield Considerations	
Year 2005 Harmonic Mean F_{msy} Yield	**1,962** t
Year 2005 Yield $F_{40\%}$ (adjusted)	**1,897** t
Full Selection F's	
F_{msy}	**0.892**
$F_{40\%}$	**0.520**
$F_{35\%}$	**0.668**

Figures

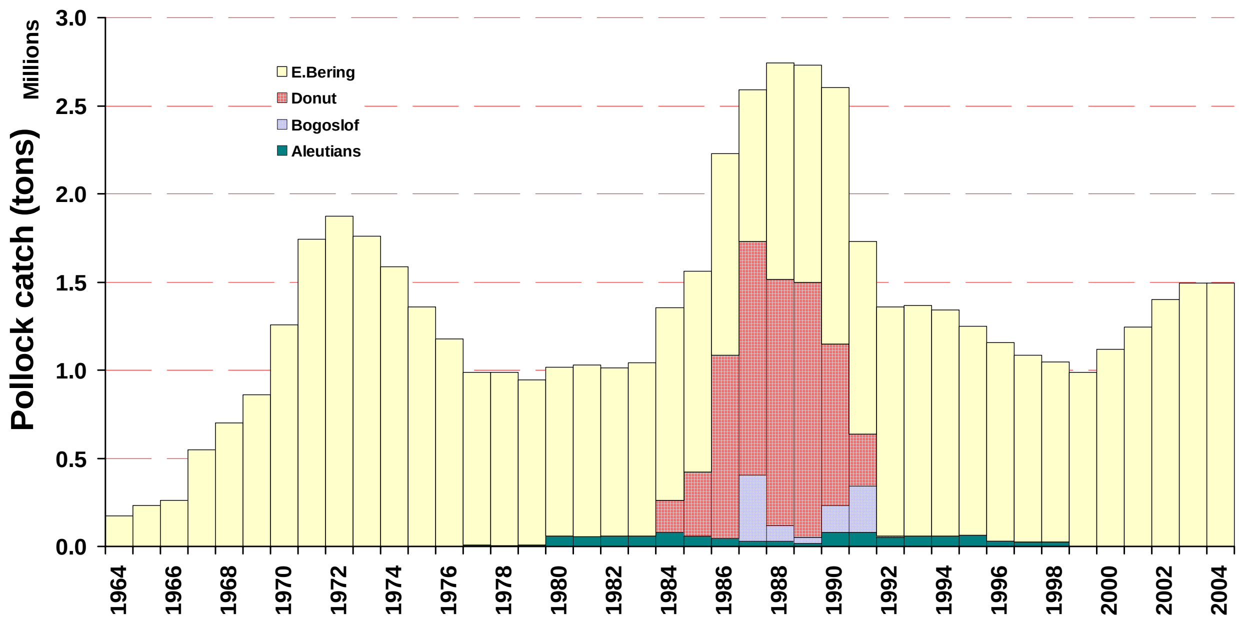


Figure 1.1. Walleye pollock catch in the eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole, 1964-2004.

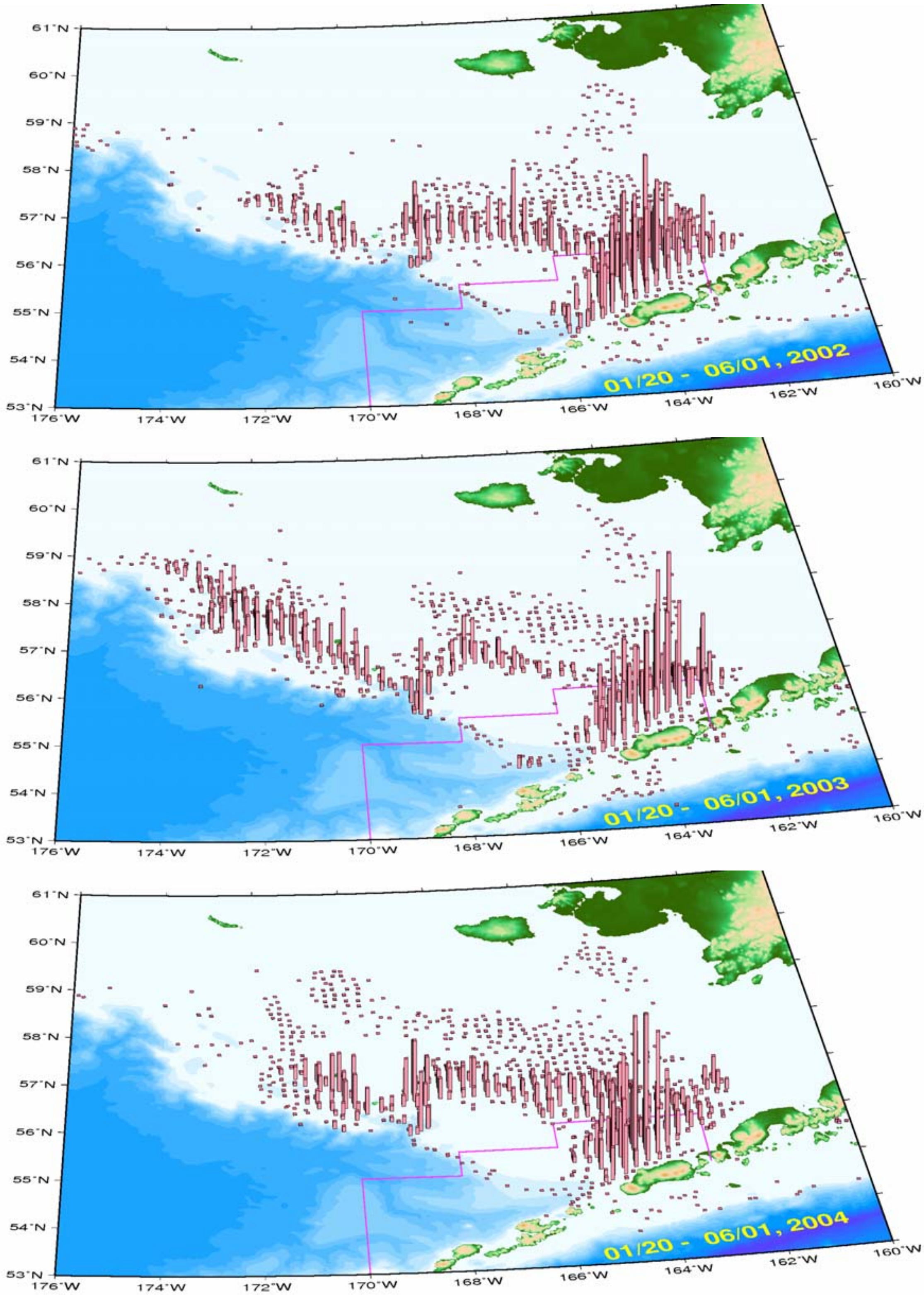


Figure 1.2. Concentrations of the pollock fishery 2002-2004, January - June on the EBS shelf. Line delineates SCA (sea lion conservation area). The column height represents relative removal on the same scale in all years.

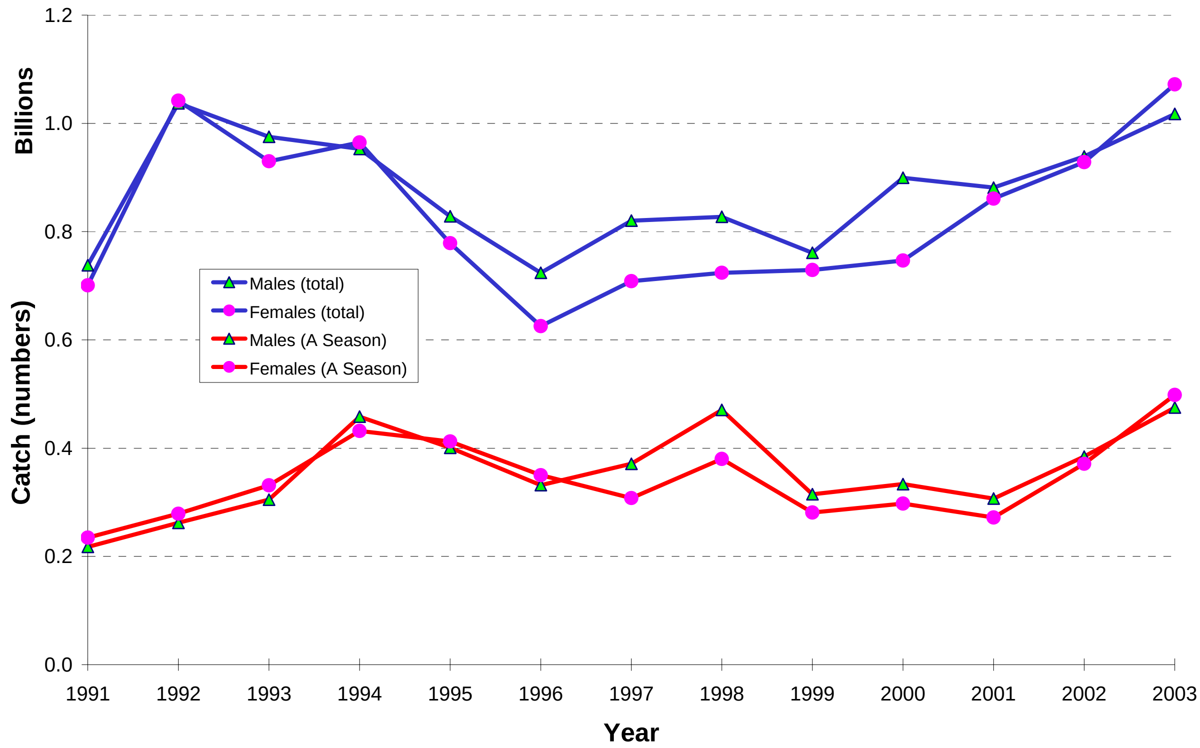


Figure 1.3. Estimate of EBS pollock catch numbers by sex for the "A season" (January-June) and for the entire annual fishery, 1991-2003.

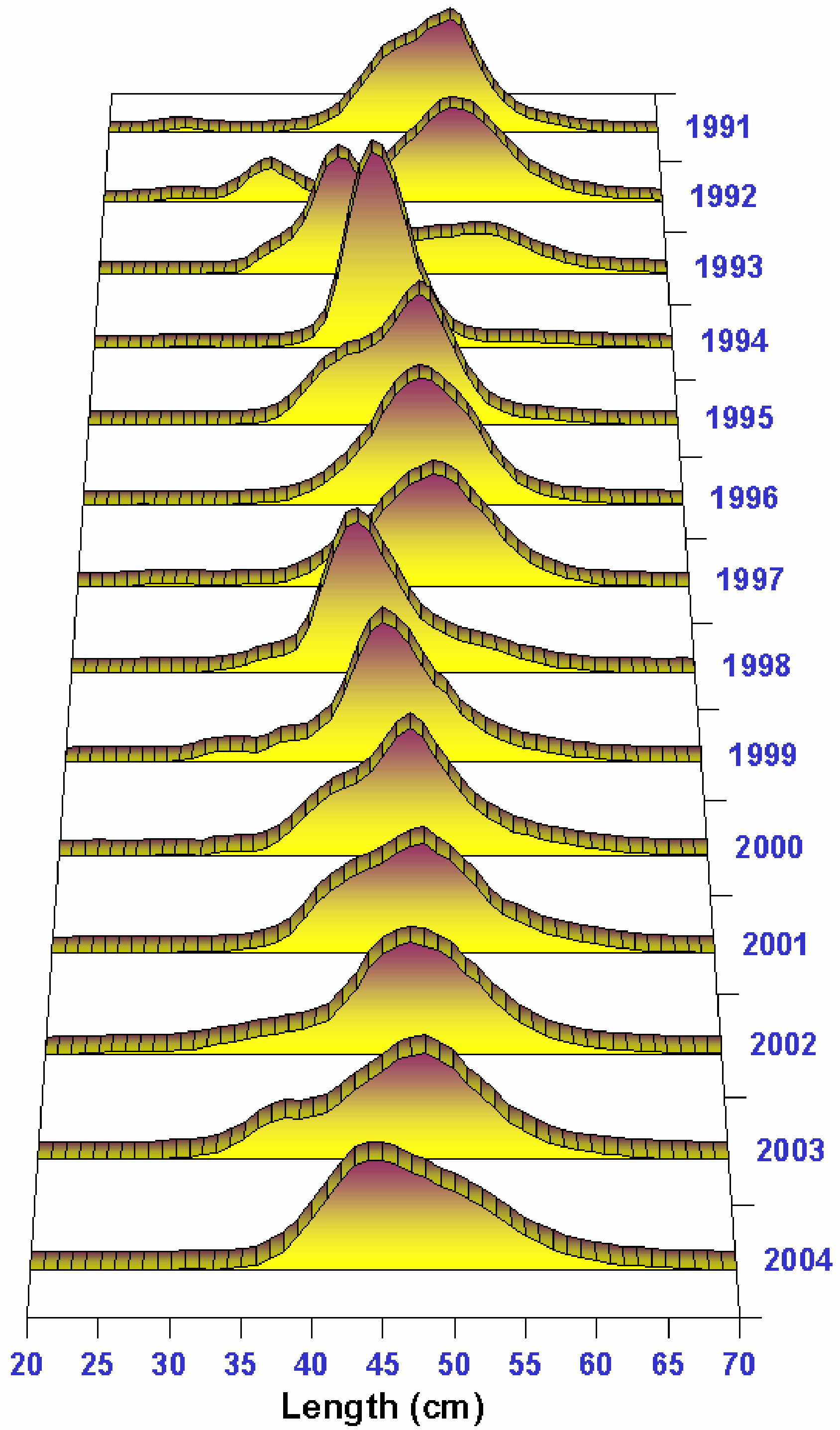


Figure 1.4. Fishery length frequency for the "A season" (January-June) female EBS pollock, 1991-2004. Data for 2004 are preliminary.

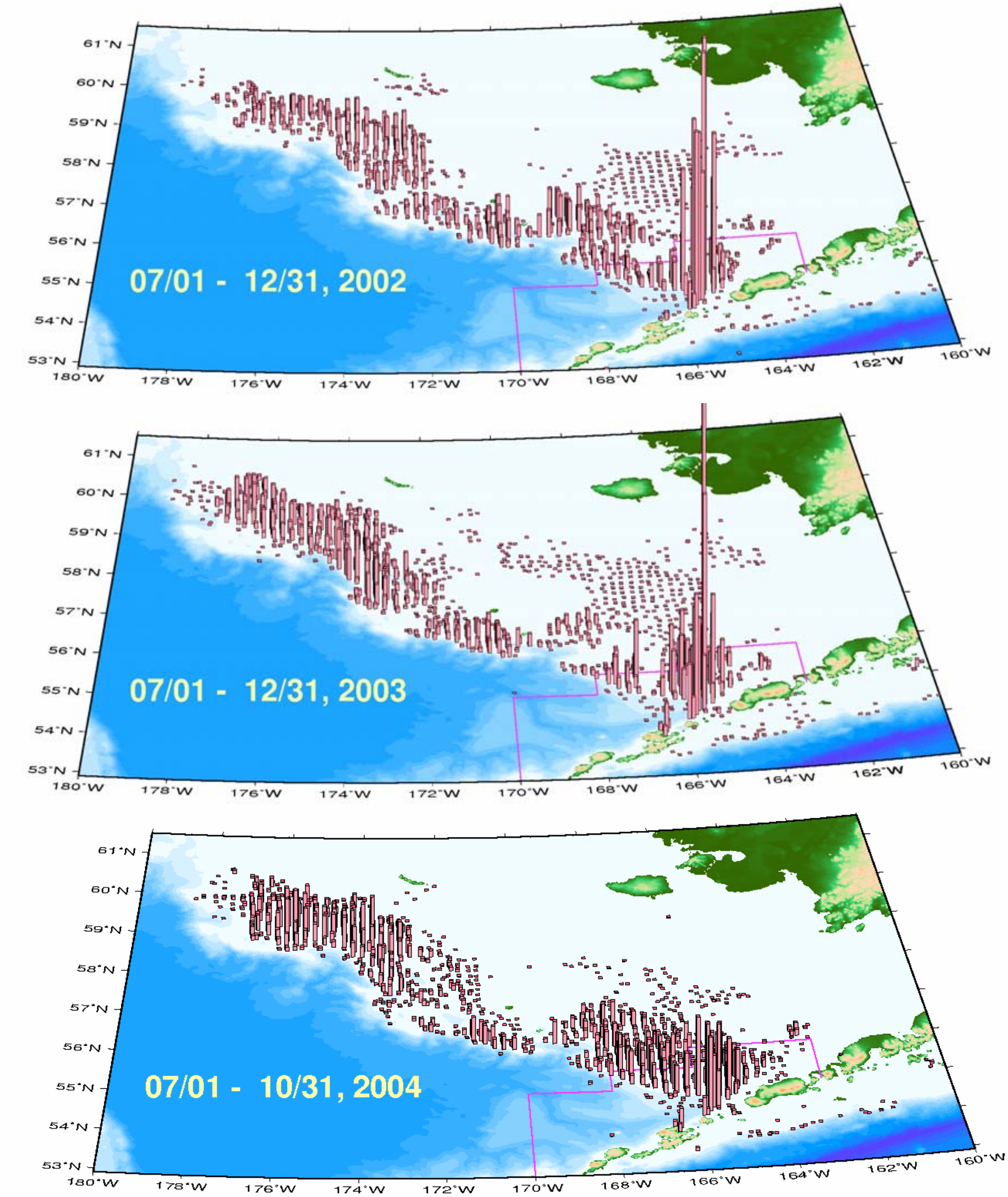


Figure 1.5. Concentrations of the pollock fishery 2002-2004, July – December (October in 2004) on the EBS shelf. Line delineates SCA (sea lion conservation area). The density represents relative removal on the same scale over all years.

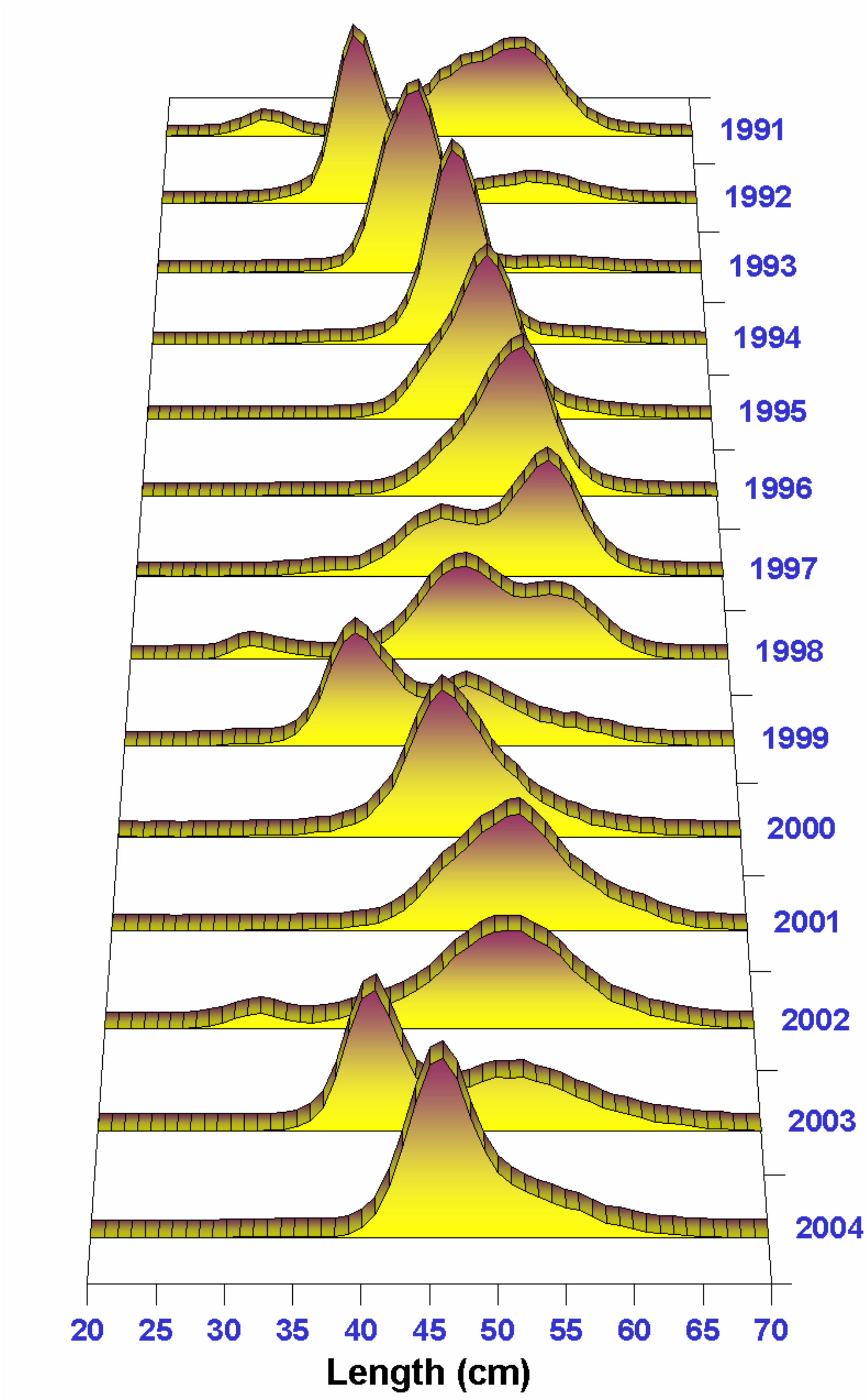


Figure 1.6. Length frequency of EBS pollock observed in period July-December (October in 2004) for 1991-2004. Data for 2004 are preliminary.

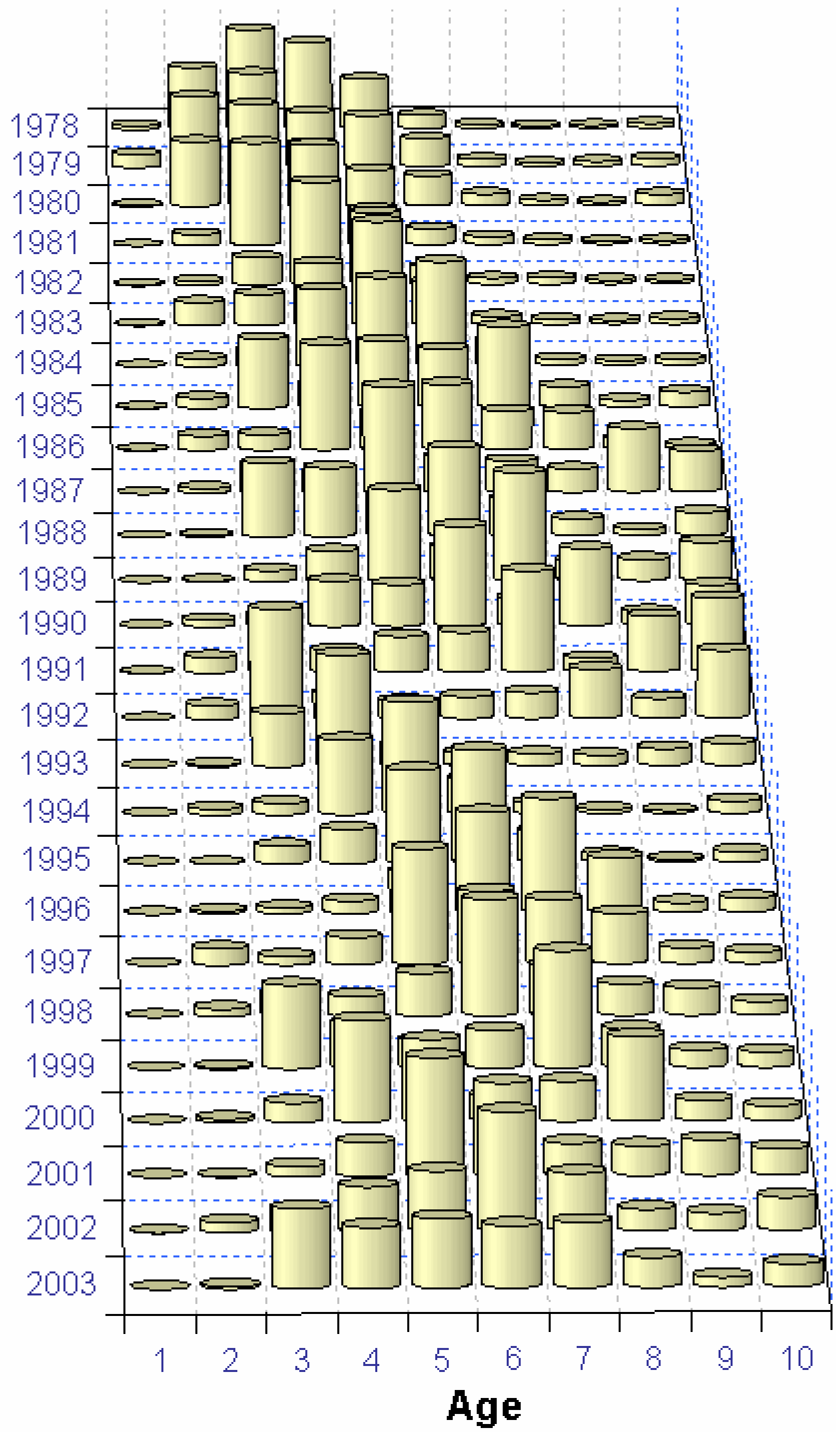


Figure 1.7. EBS walleye pollock fishery estimated catch-at-age data (proportions) for 1978-2003. Age 10 represents pollock age 10 and older.

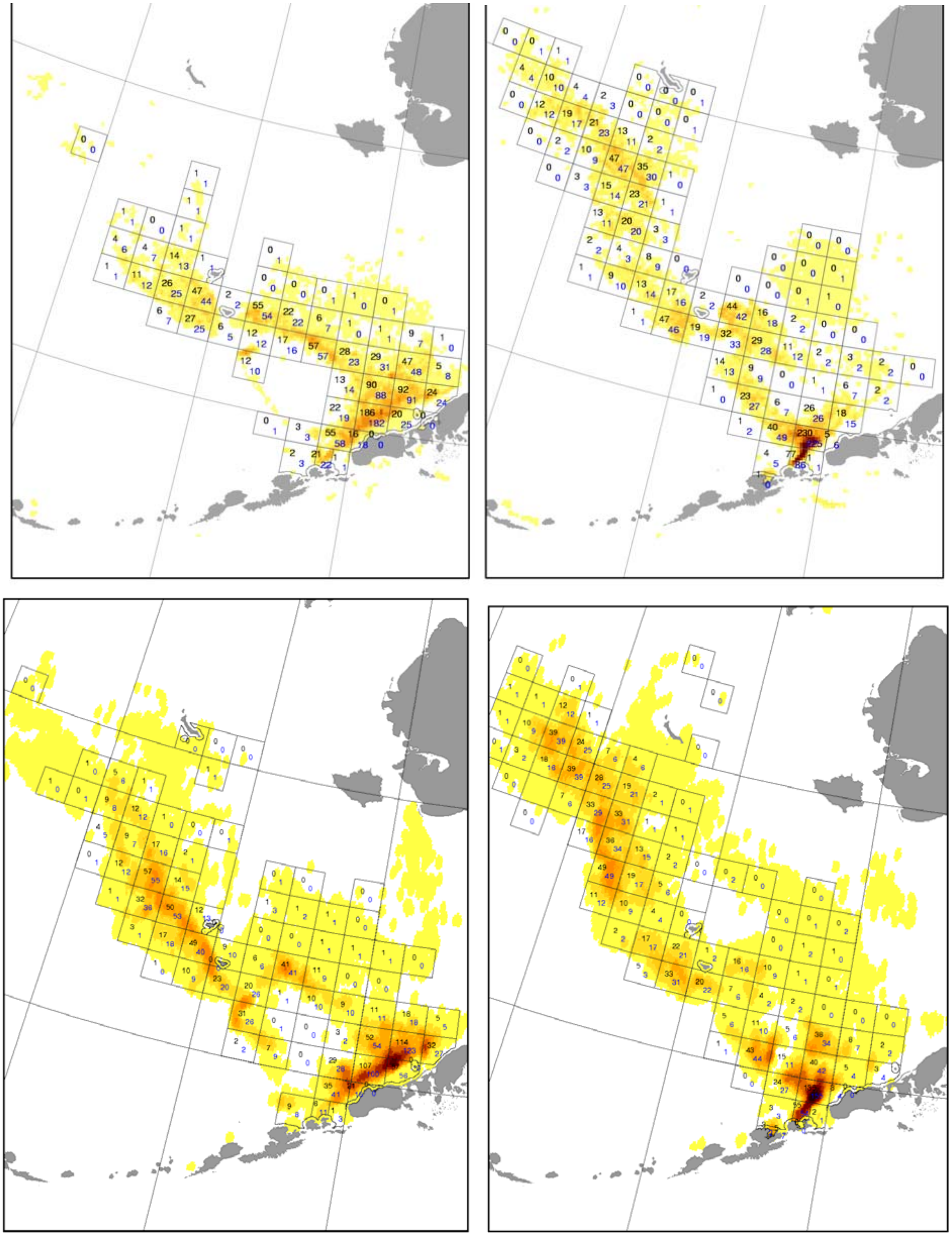


Figure 1.8. Sampling effort for lengths (upper left corner of grids) and otoliths (lower right corner of grids) of pollock in the EBS during 2002 (upper panels) and 2003 (lower panels). Values represent the number-per-thousand of samples within each cell divided by the total number of samples for Jan-June (left panels) and July-Dec (right panels).

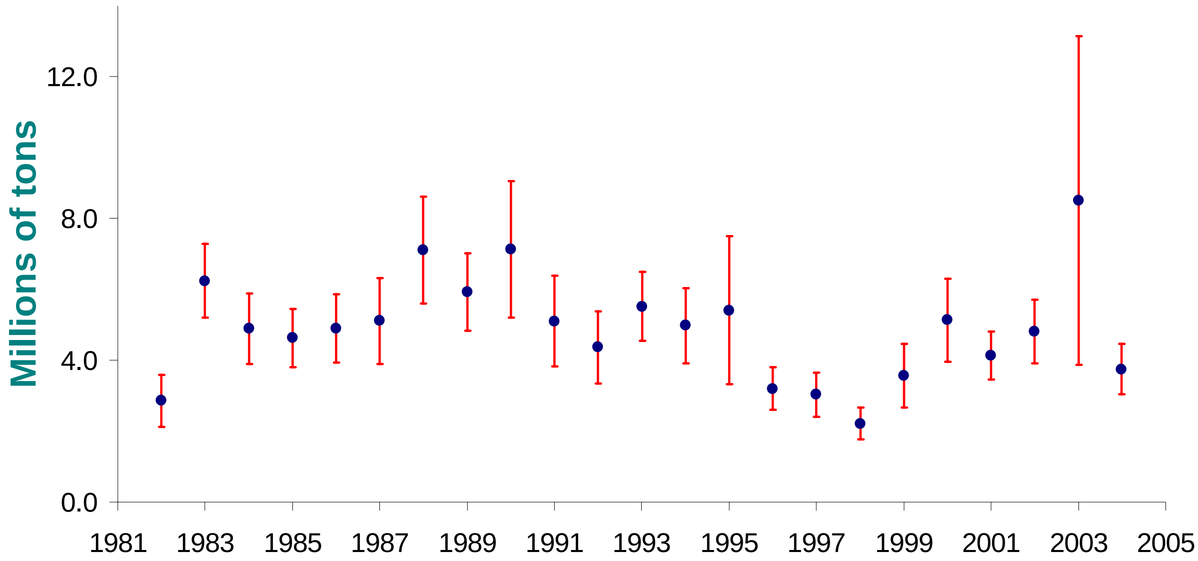
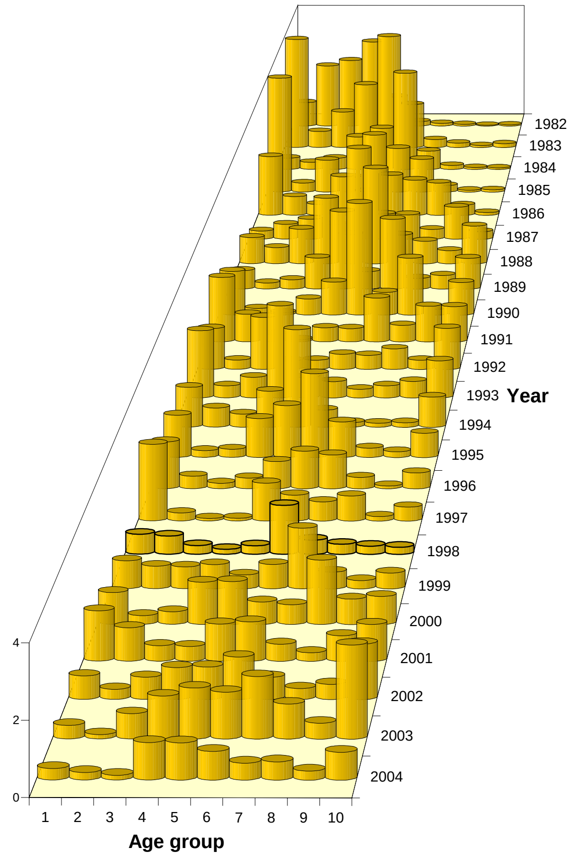


Figure 1.9. Bottom-trawl survey biomass estimates with approximate 95% confidence bounds (based on sampling error) for EBS walleye pollock, 1982-2004.



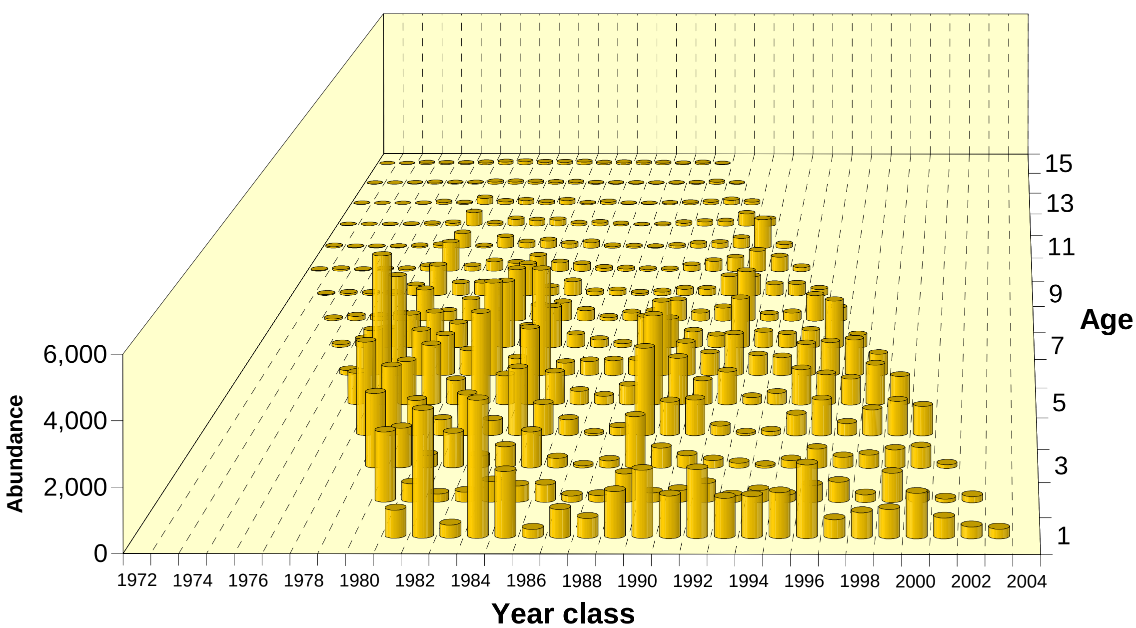


Figure 1.10. Pollock abundance levels by age and year plotted over time (top) and by individual cohorts (year classes) as estimated directly from the NMFS bottom-trawl surveys (1982-2004).

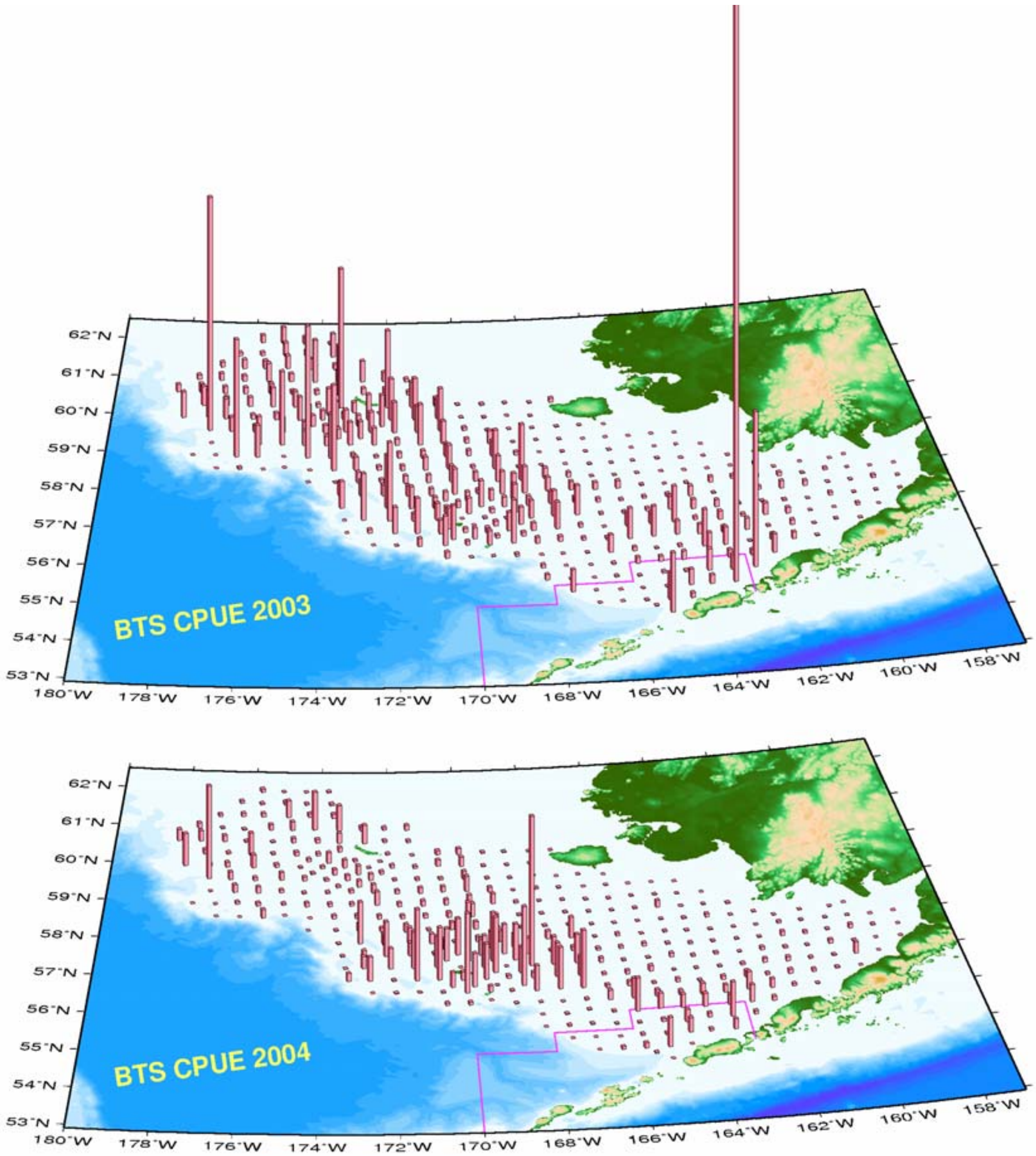


Figure 1.11. Maps showing the walleye pollock catch-per-unit effort observed from the 2003 and 2004 NMFS EBS shelf bottom-trawl surveys.

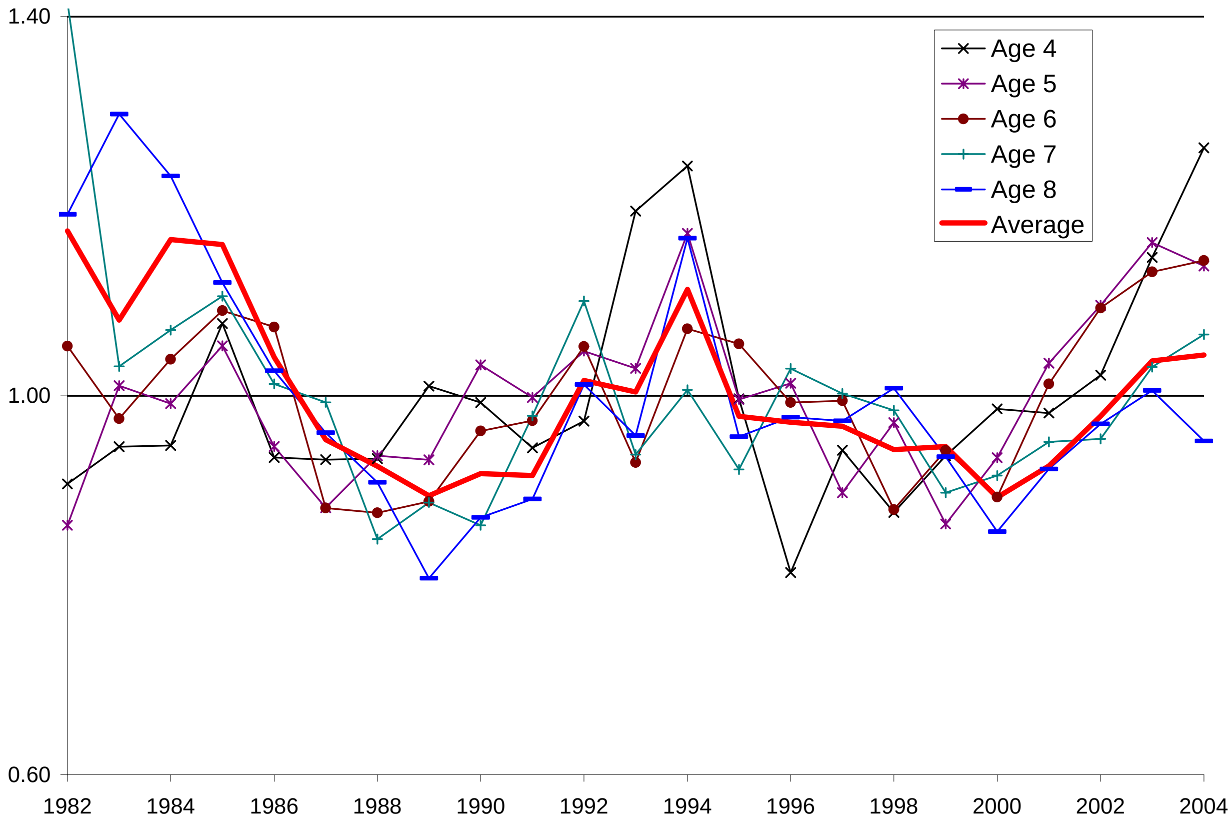


Figure 1.12. Trends in pollock average weights-at-age based on NMFS bottom trawl survey estimates, 1982-2004. Values are shown relative to their mean within each age or age group. Note that the length-weight relationship used here is constant; hence, the differences are how average lengths-at-age vary over time in terms of weight.

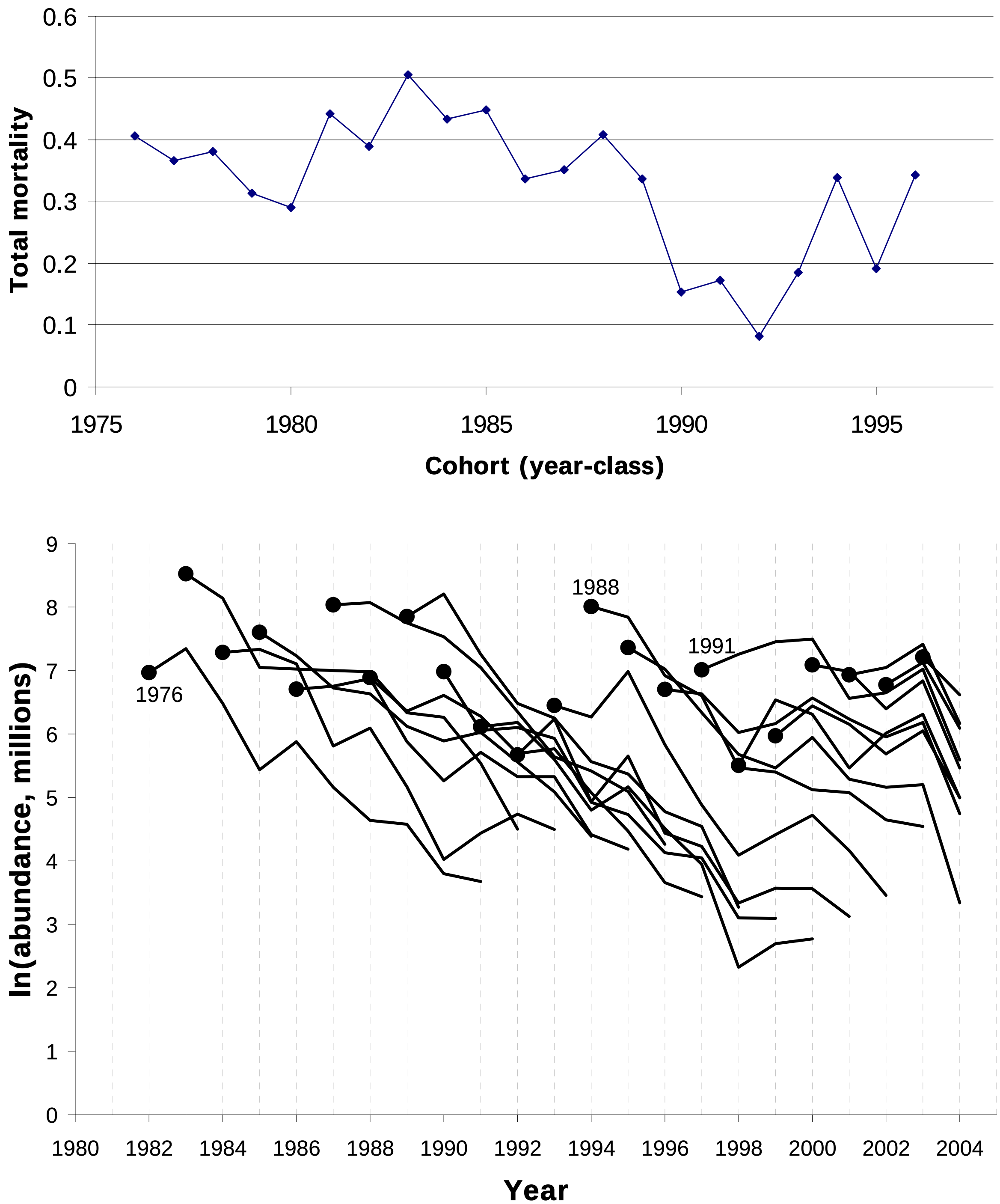


Figure 1.13. Evaluation of cohort abundances as observed for age 6 and older in the NMFS summer bottom trawl surveys. The bottom panel shows the raw log-abundances at age while the top panel shows the estimates of total mortality by cohort.

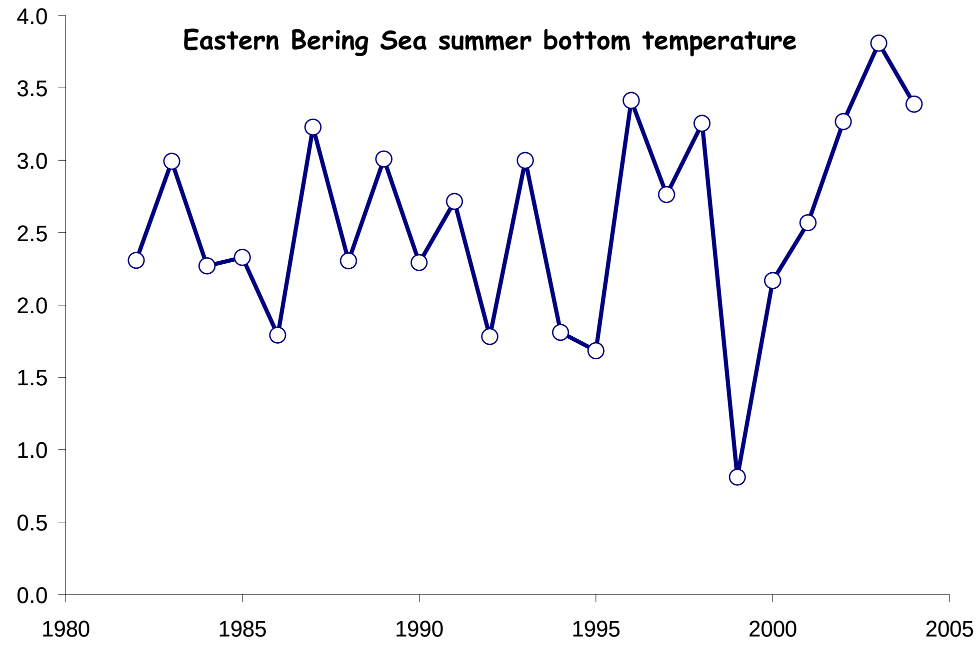


Figure 1.14. Mean summer bottom temperatures used to model bottom trawl survey pollock catchability, 1982-2004. (Note: these were normalized to have mean zero for use in the model).

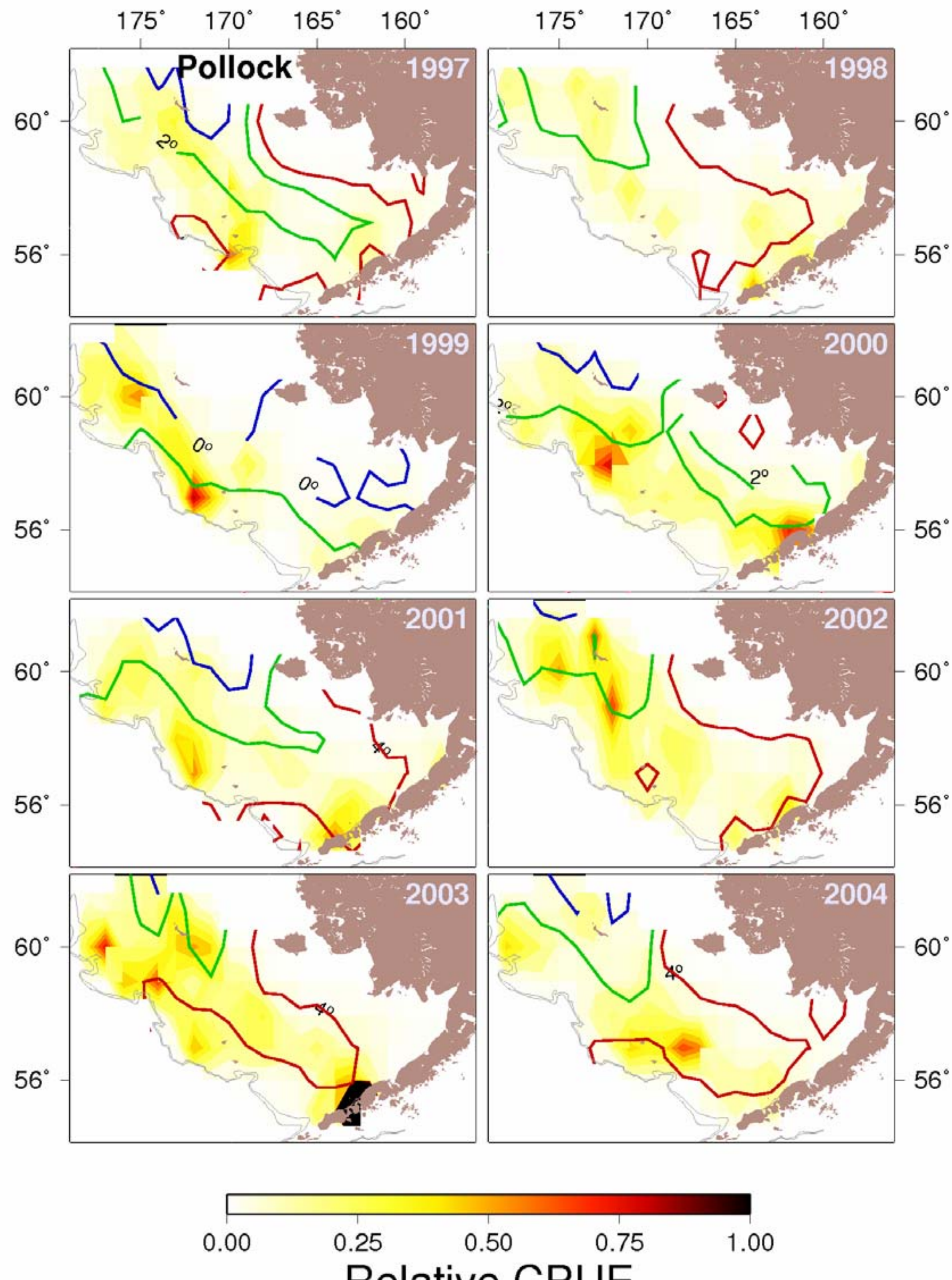


Figure 1.15. EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms of 0º, 2º, and 4º Celsius for 1997-2004. Station locations are depicted by the dots.

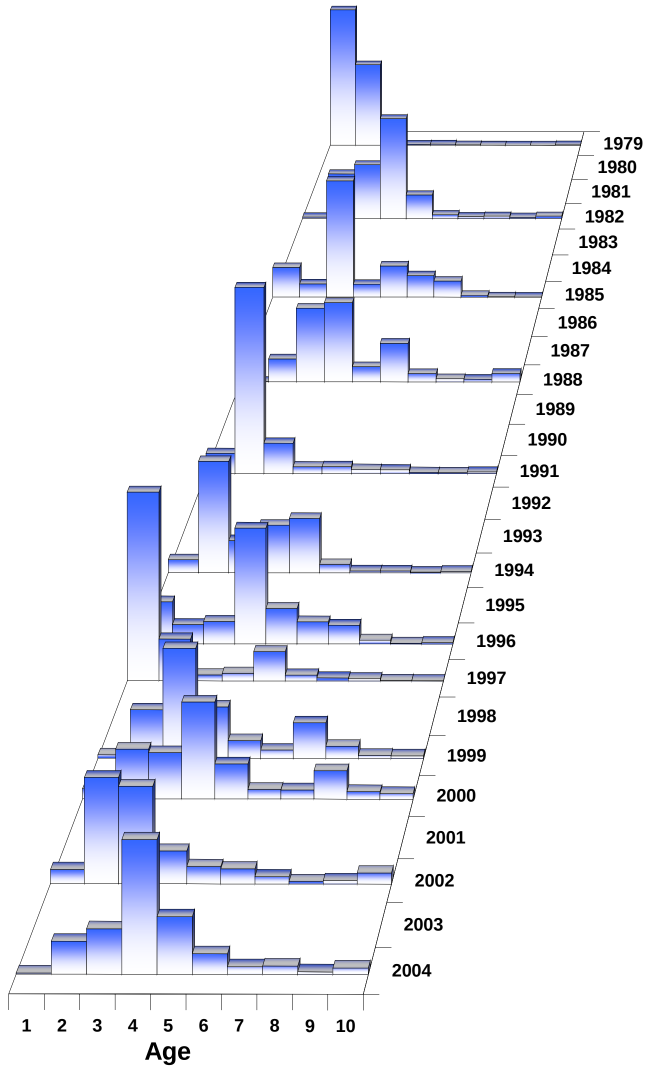


Figure 1.16. Time series of estimated proportions at age for EBS walleye pollock from the EIT surveys, 1979-2004. Note: 2004 estimates represent age distributions derived from age-length keys from the 2004 BTS age data.

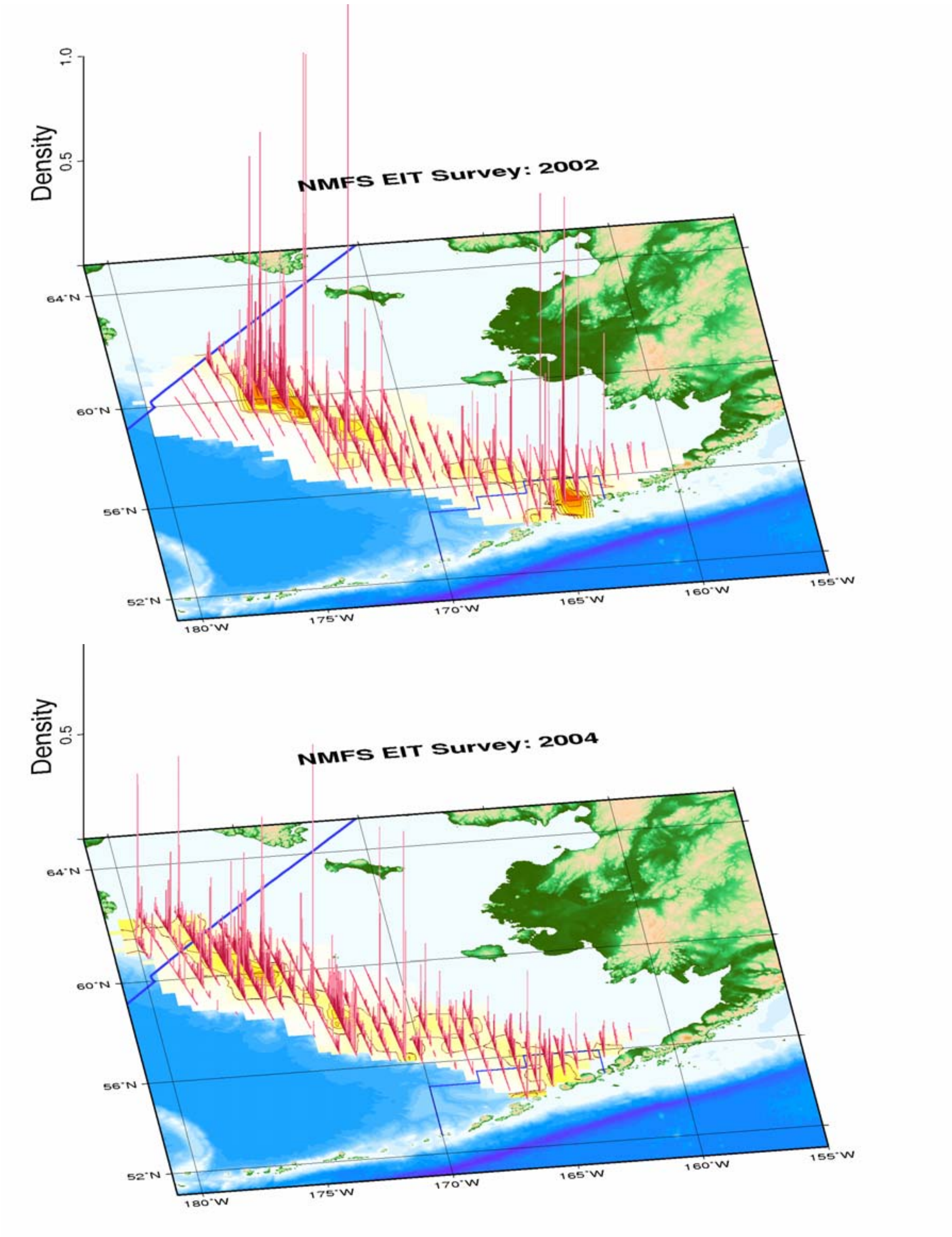


Figure 1.17. Echo-integration trawl survey results for 2002 and 2004. Vertical lines represent biomass of pollock as observed using acoustic methods.

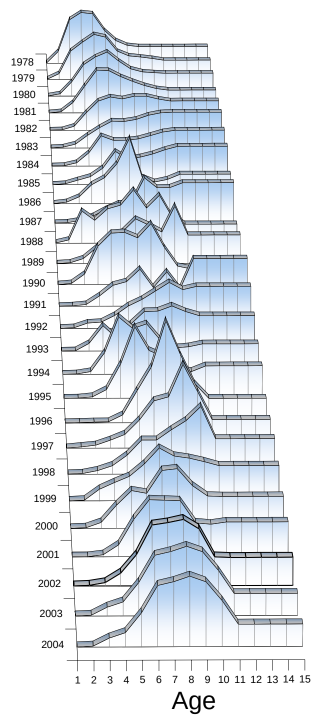


Figure 1.18. Model 3 EBS pollock fishery selectivity-at-age estimates, 1978-2004. Model 3 assumed that the fishery catch-at-age data are measured precisely.

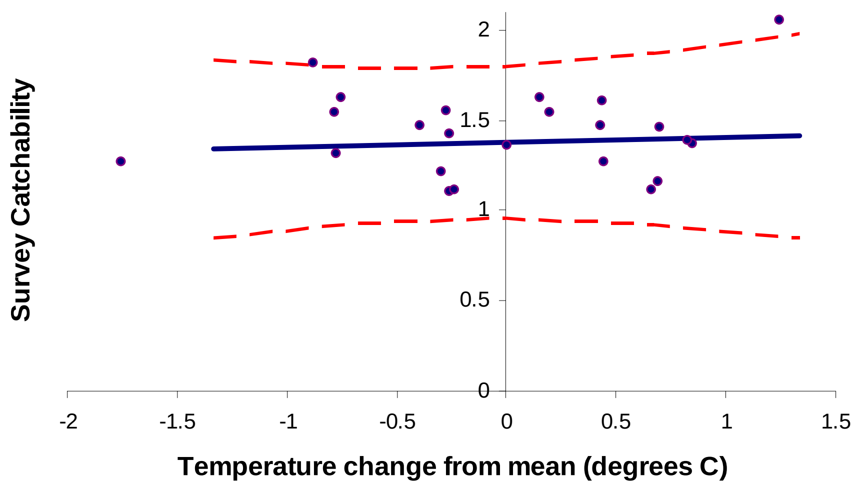


Figure 1.19. Estimated relationship between pollock bottom-trawl survey catchability and bottom temperature (normalized to have a mean value of 0) as under Model 4. Points represent residuals relative to survey estimates (i.e., $\hat{q}_t + \ln\left(\hat{I}_t / I_t\right)$ where $\hat{I}_t$ and I_t represent the predicted and observed survey indices respectively and $\hat{q}_t$ is the expected catchability given the temperature anomaly in year *t*.

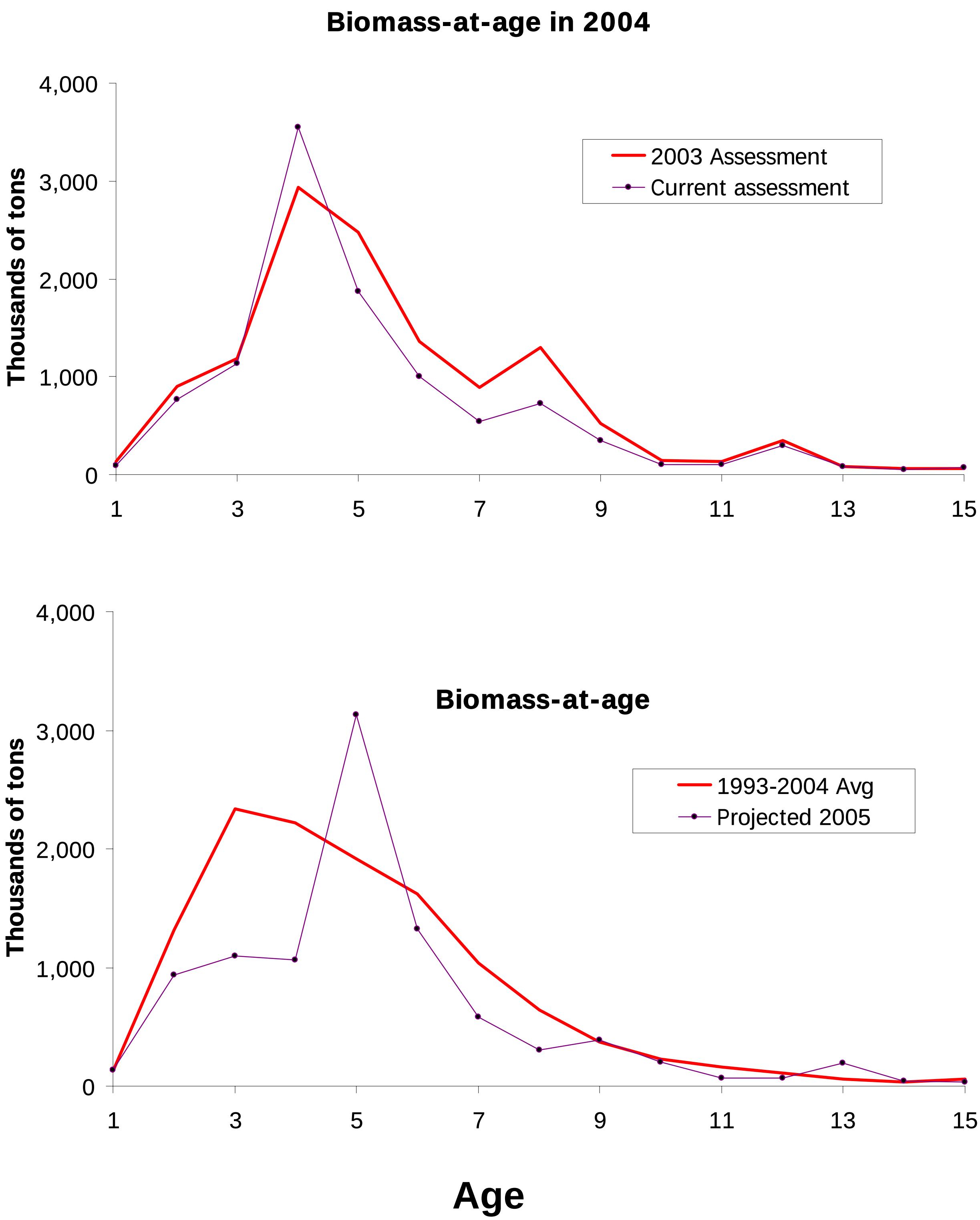


Figure 1.20. Estimates of 2004 biomass-at-age from the 2003 assessment compared to the current assessment (top panel) for EBS walleye pollock Model 1 and the projection for 2005 (from the current assessment) compared to the average population biomass-at-age from 1993-2004 (lower panel).

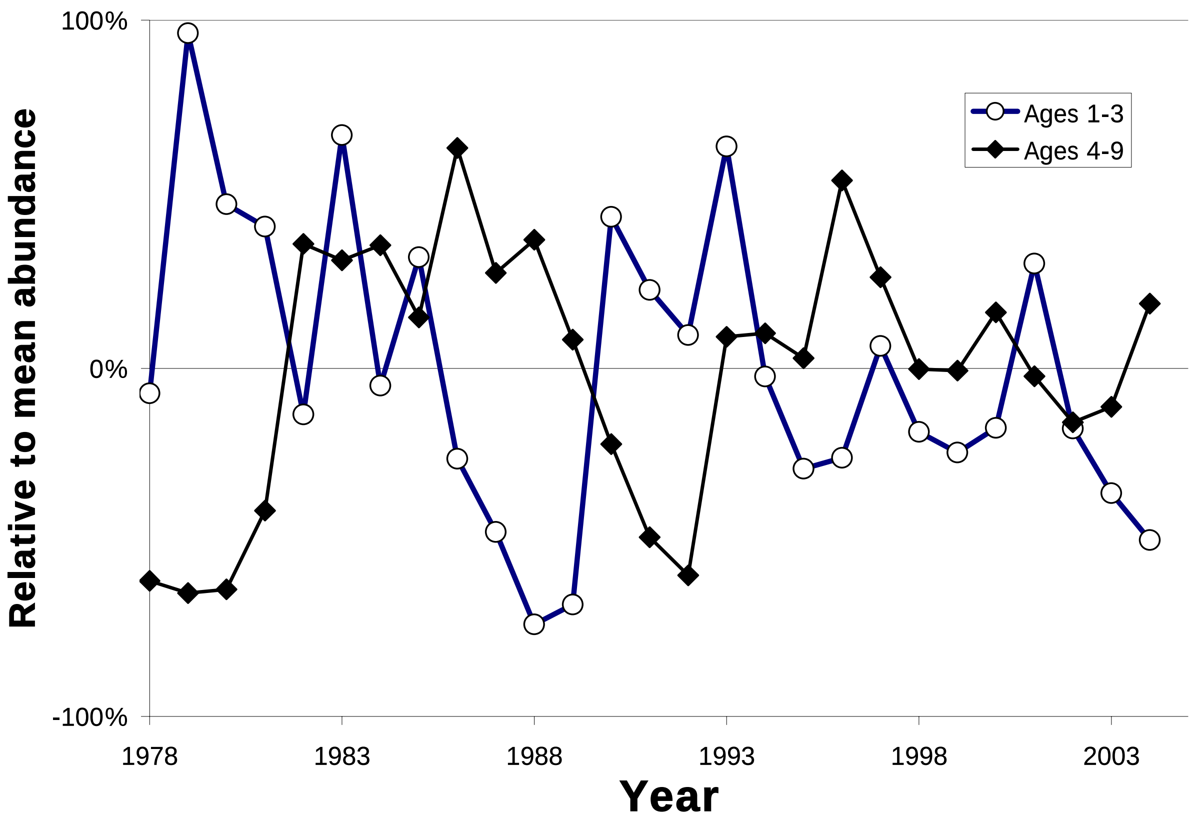


Figure 1.21. Model 1 relative abundance estimates of young pollock and mid-age pollock, 1978-2004. The values are relative to the mean model abundances of these age groups.

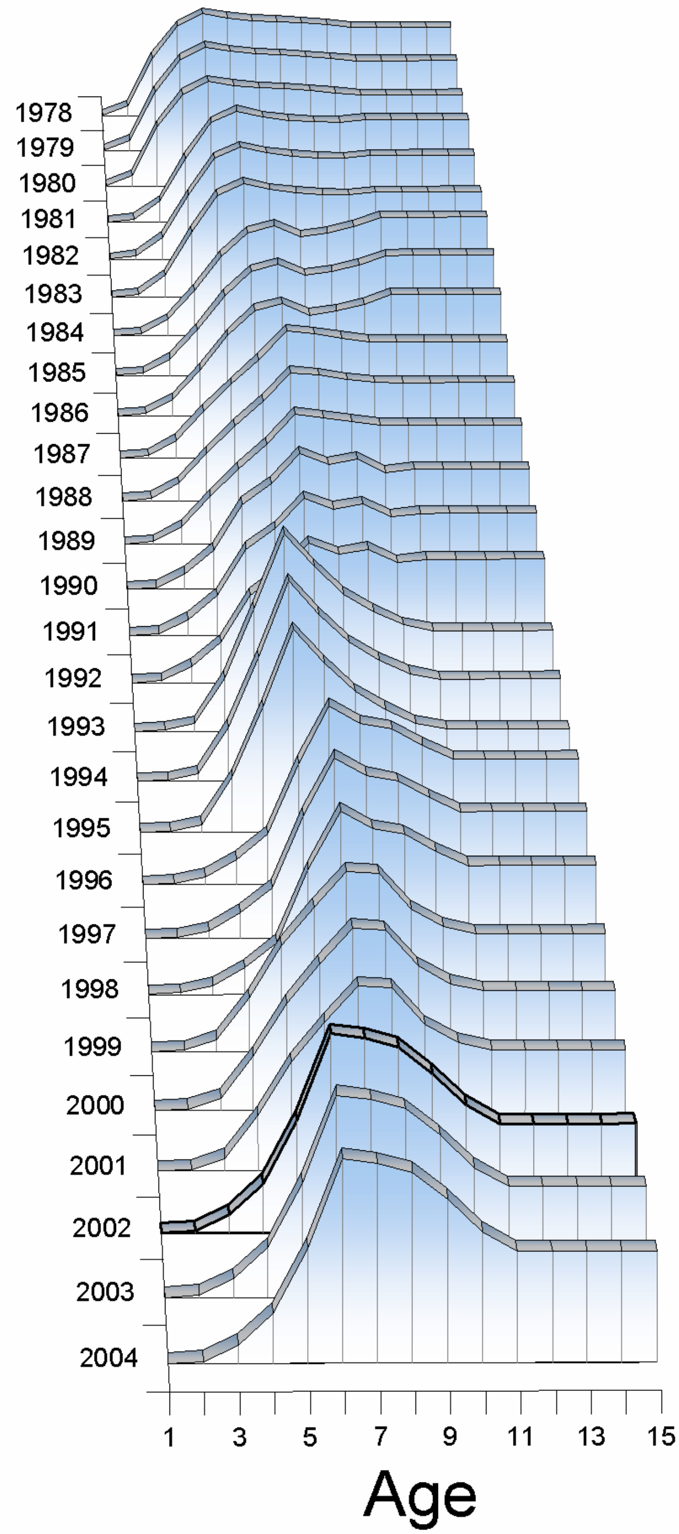


Figure 1.22. Selectivity at age estimates for the EBS walleye pollock fishery, 1978-2004 estimated for Model 1.

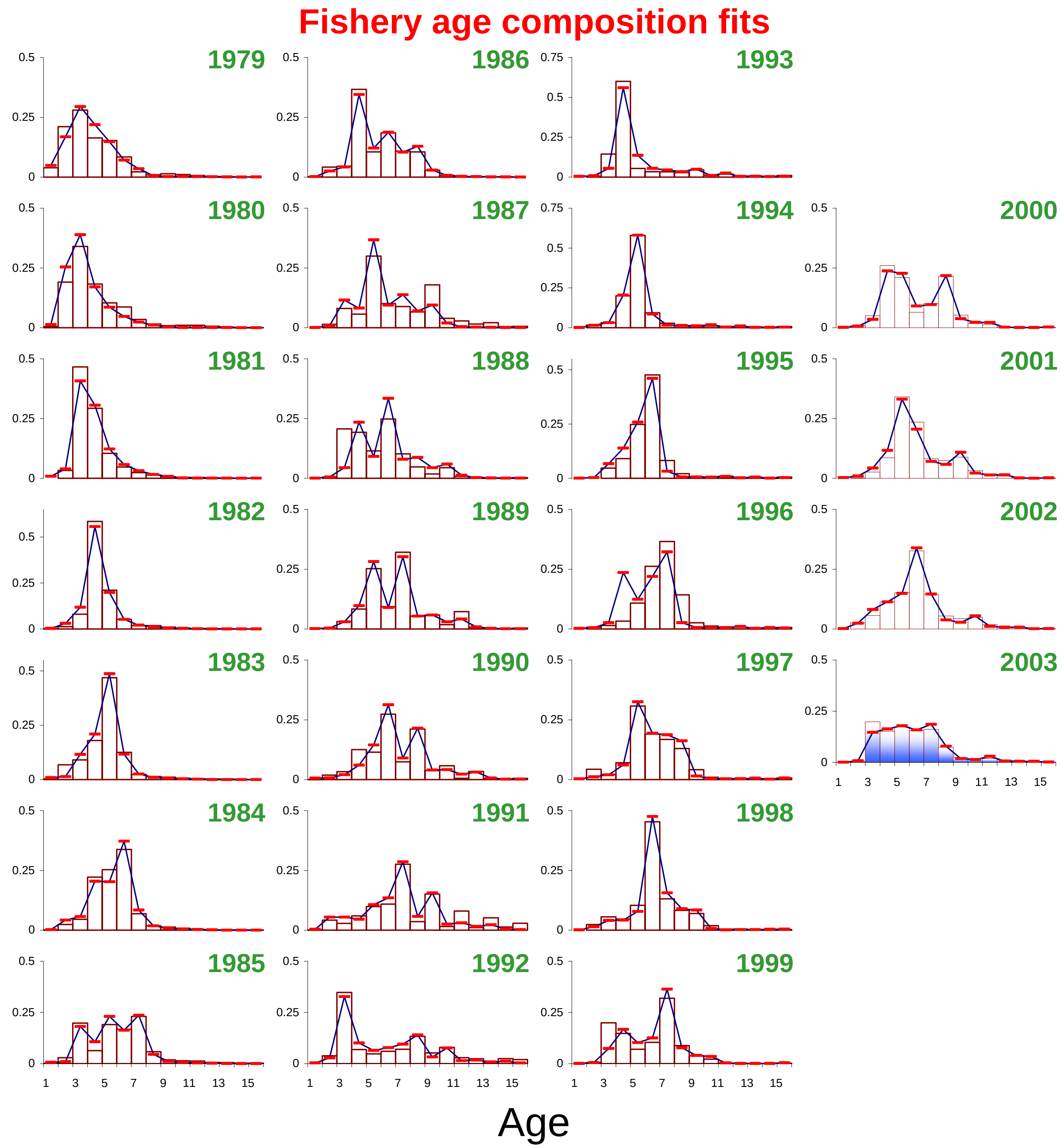


Figure 1.23. Model 1 fit to the EBS walleye pollock fishery age composition estimates (1979-2003). Lines represent model predictions while the vertical columns represent the data. Data new to this year's assessment are shaded.

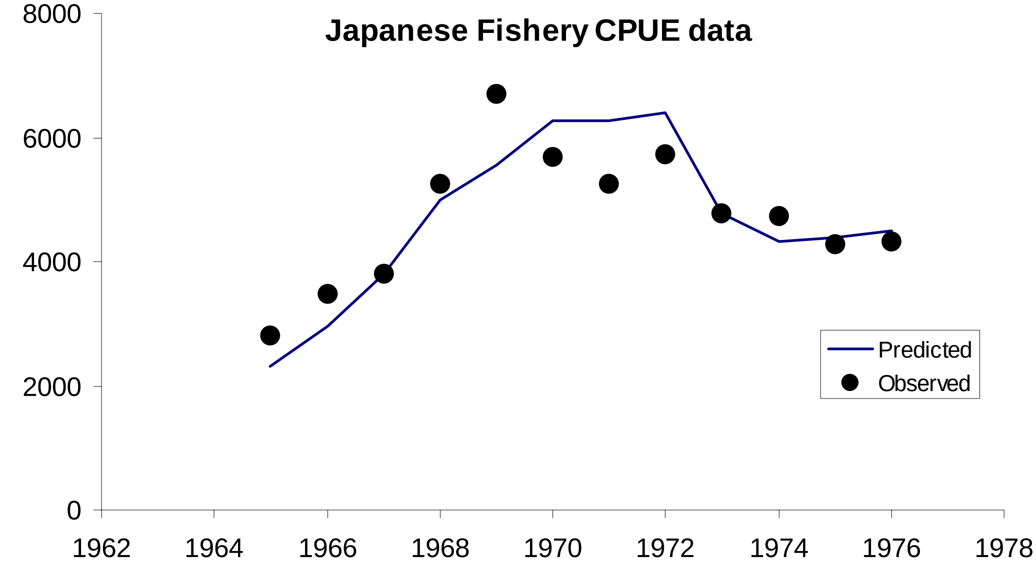


Figure 1.24. Model 1 fit to the EBS walleye pollock fishery CPUE data from Low and Ikeda (1980).

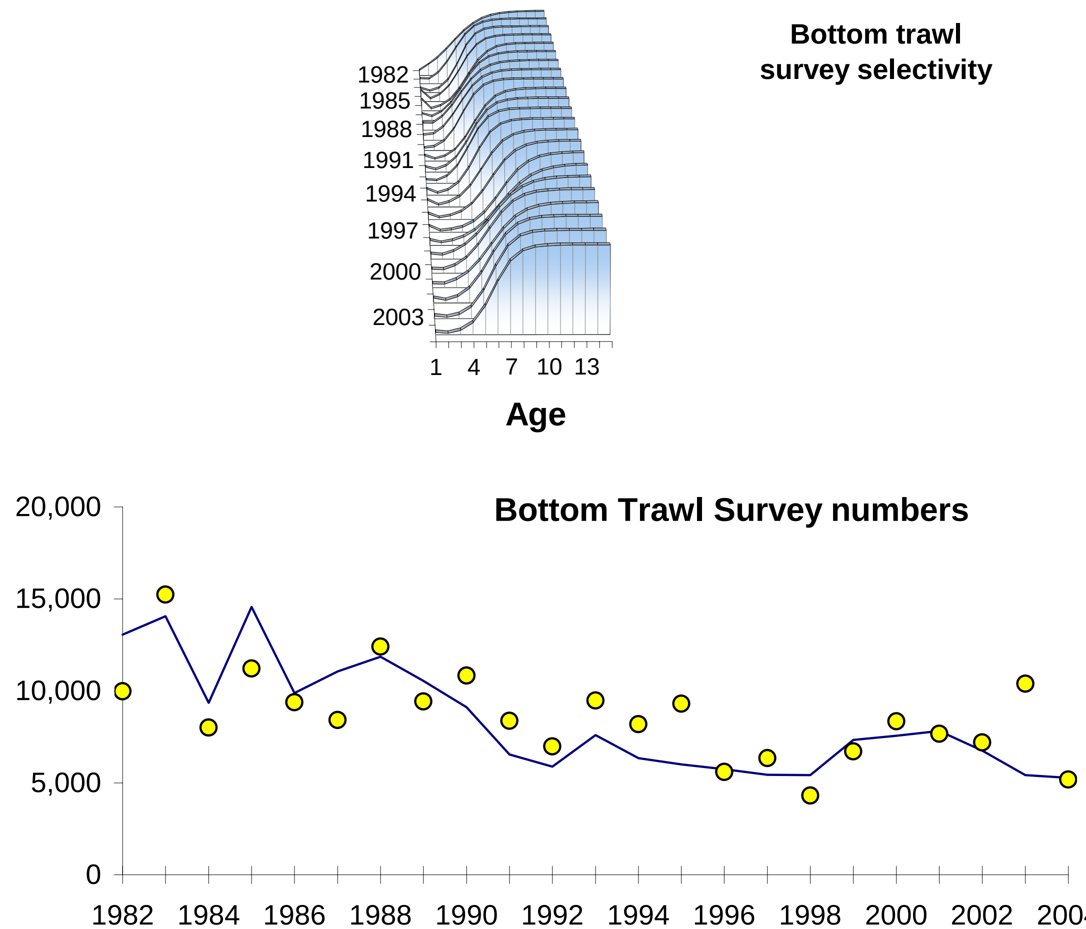


Figure 1.25. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age (with maximum value equal to 1.0) over time (upper panel) for EBS walleye pollock, 1982-2004, Model 1.

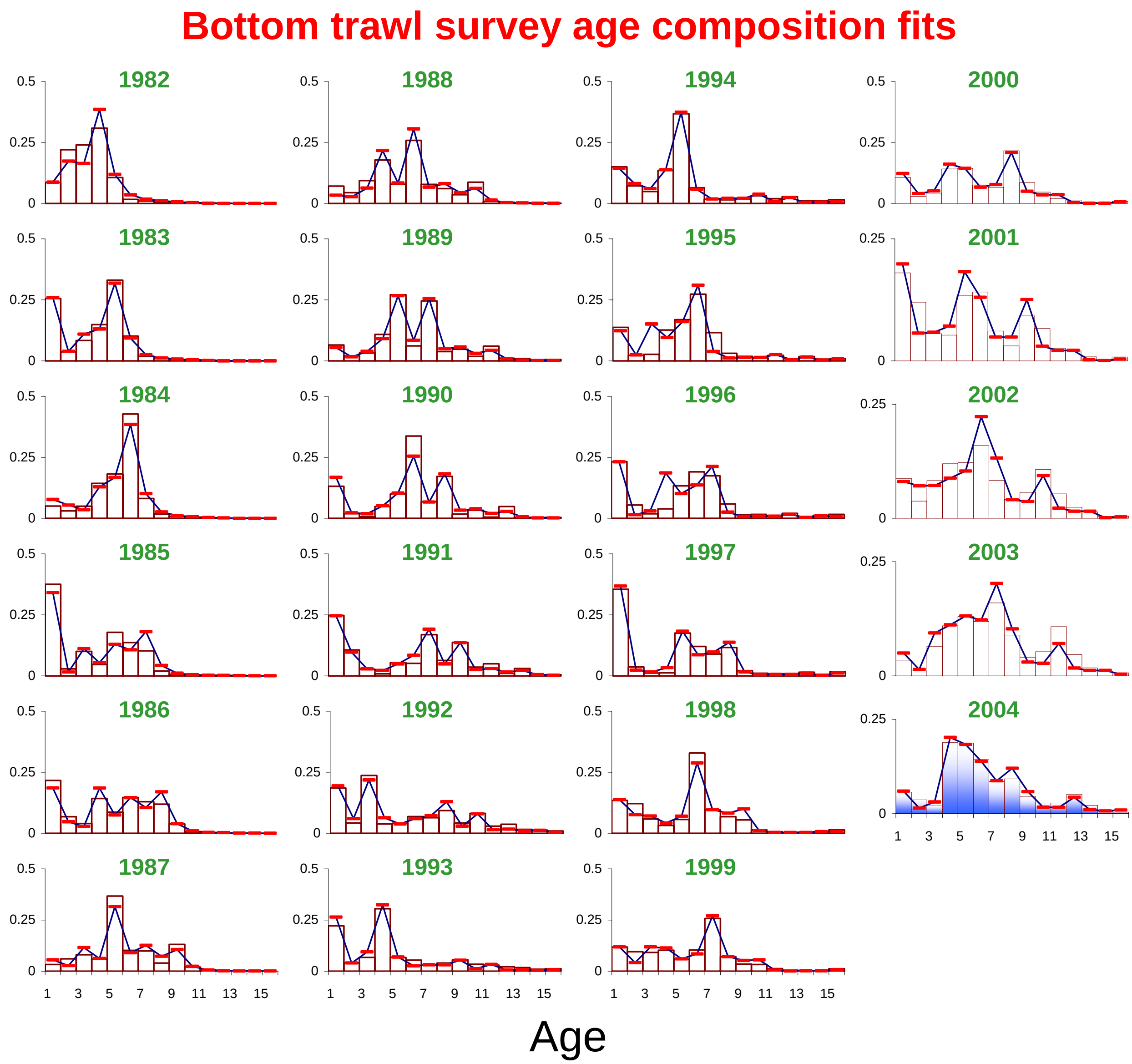
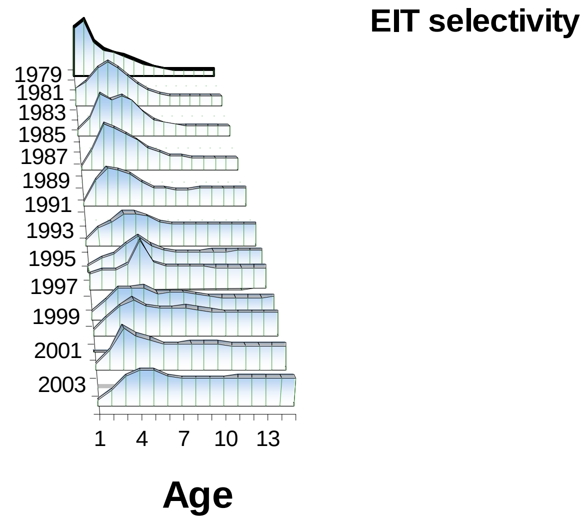


Figure 1.26. Model 1 fit to the bottom trawl survey age composition data (proportions) for EBS walleye pollock. Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded (2004).



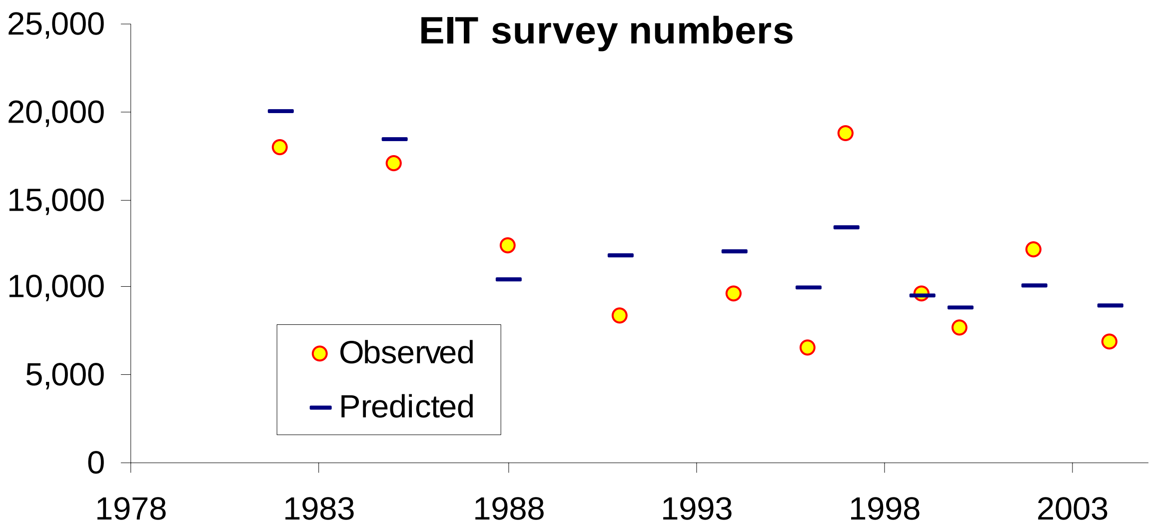


Figure 1.27. Model 1 estimates of EIT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock. Note that the 1979 value (observed=115,424; predicted=48,979) are not plotted.

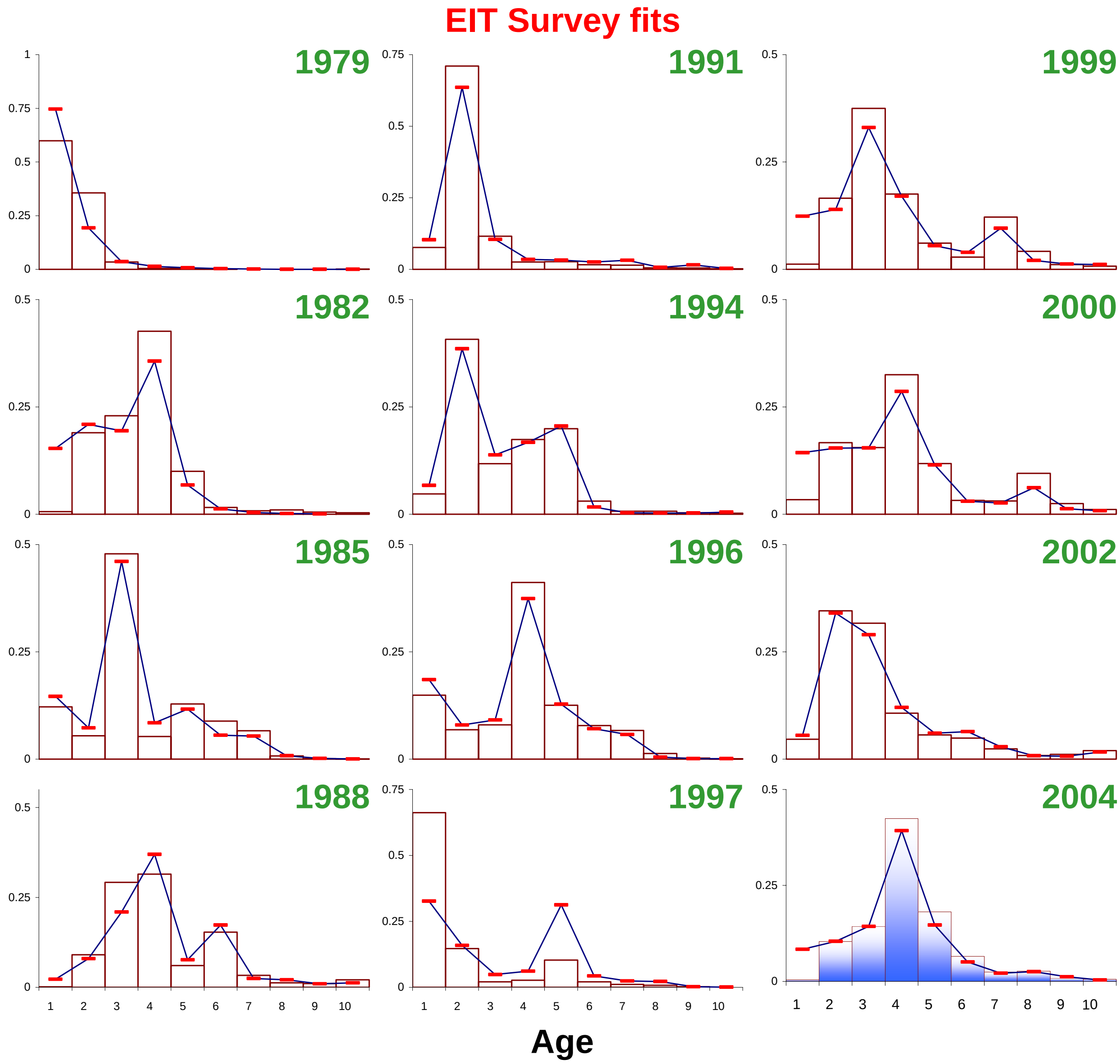


Figure 1.28. Model 1 fit to the EIT survey EBS walleye pollock age composition data (proportions). Lines represent model predictions while the vertical columns represent the data. Data new to the assessment are shaded. Note: 2004 age composition data was constructed by applying the 2004 bottom-trawl survey age-length key to the EIT length frequencies.

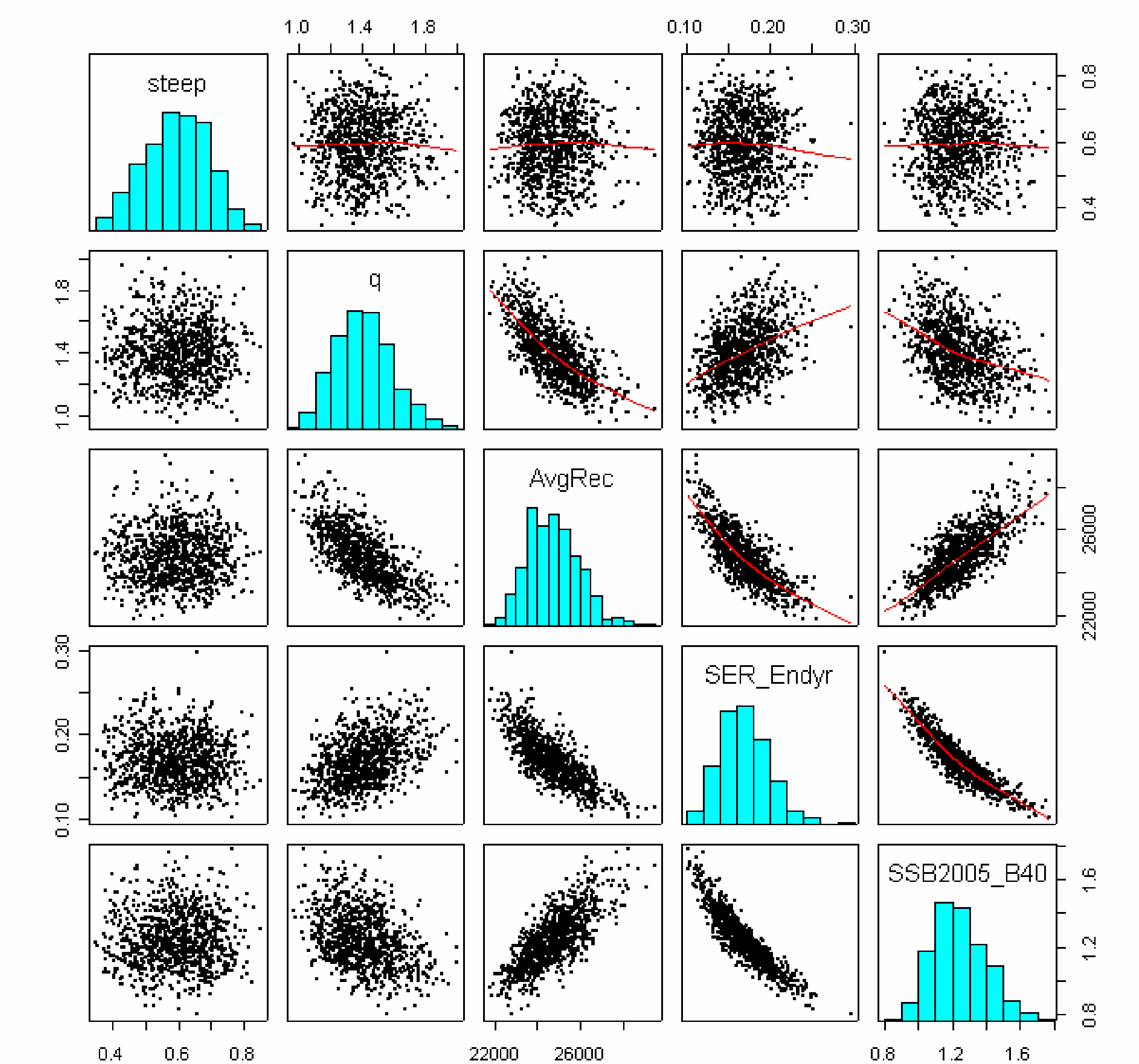
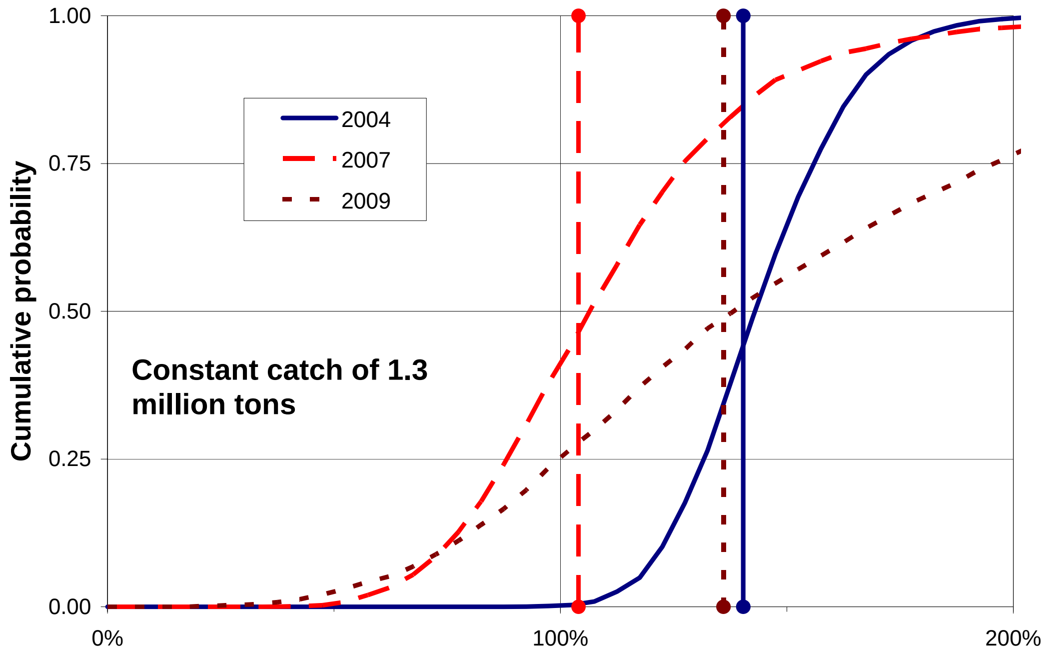


Figure 1.29. Bivariate and marginal distributions of key parameters integrated over an MCMC chain for Model 1 (length two million with every 400th sample selected and a burn-in of 4,000).



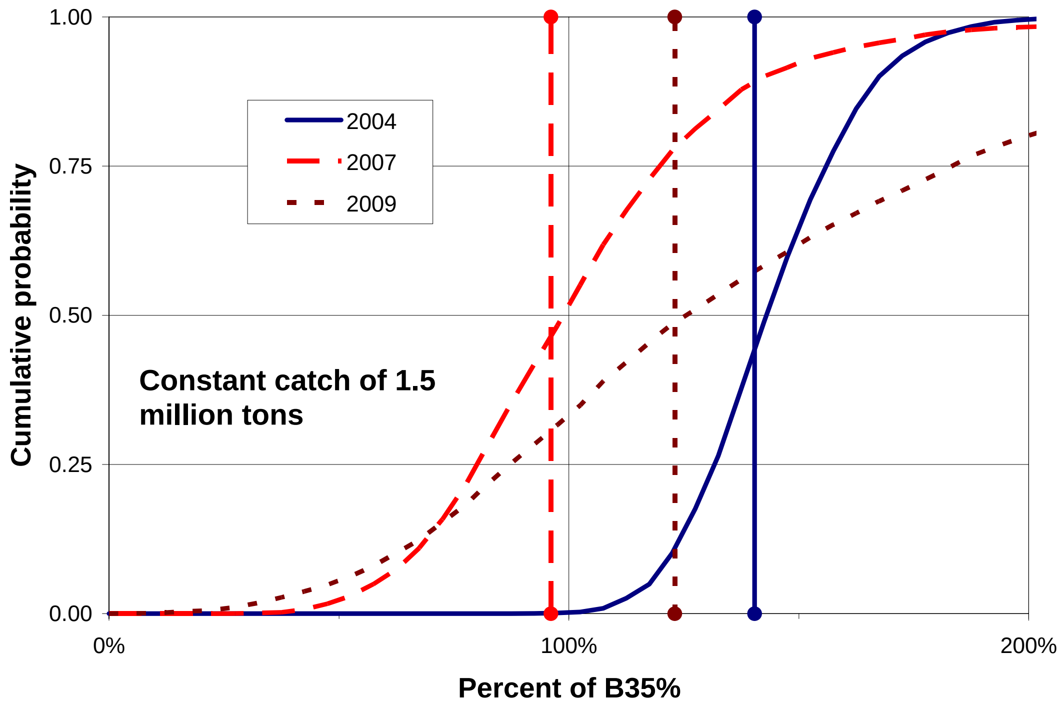


Figure 1.30. Cumulative probability that projected female spawning biomass levels will drop below $B_{35\%}$ based on a fixed constant catch levels of 1.3 (top) and 1.5 (bottom) million tons. Marginal distributions from the full joint posterior distribution are based on a thinned MCMC chain used for integration (5,000 out of 2 million). Corresponding expected values (means) are shown by the vertical lines terminated with closed circles.

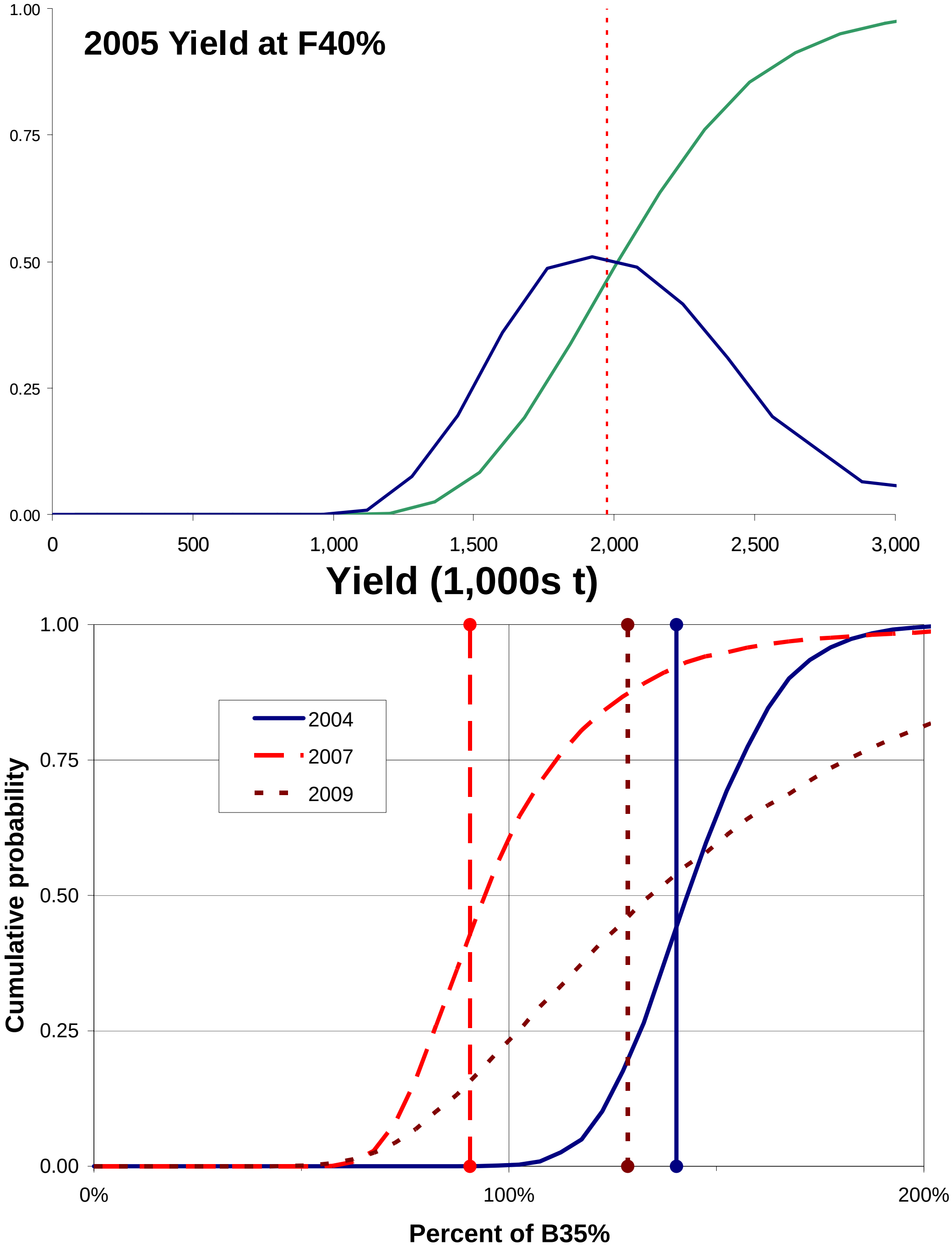


Figure 1.31. Probability distribution of 2005 yield (thousands of tons) at $F_{40\%}$ for EBS pollock (top panel) and cumulative probabilities that projected female spawning biomass levels will drop below $B_{35\%}$ based on a fixed $F_{40\%}$ harvest rate policies. Marginal distributions from the full joint posterior distribution are based on a thinned MCMC chain used for integration. Corresponding expected values (means) are shown by the vertical lines terminated with closed circles.

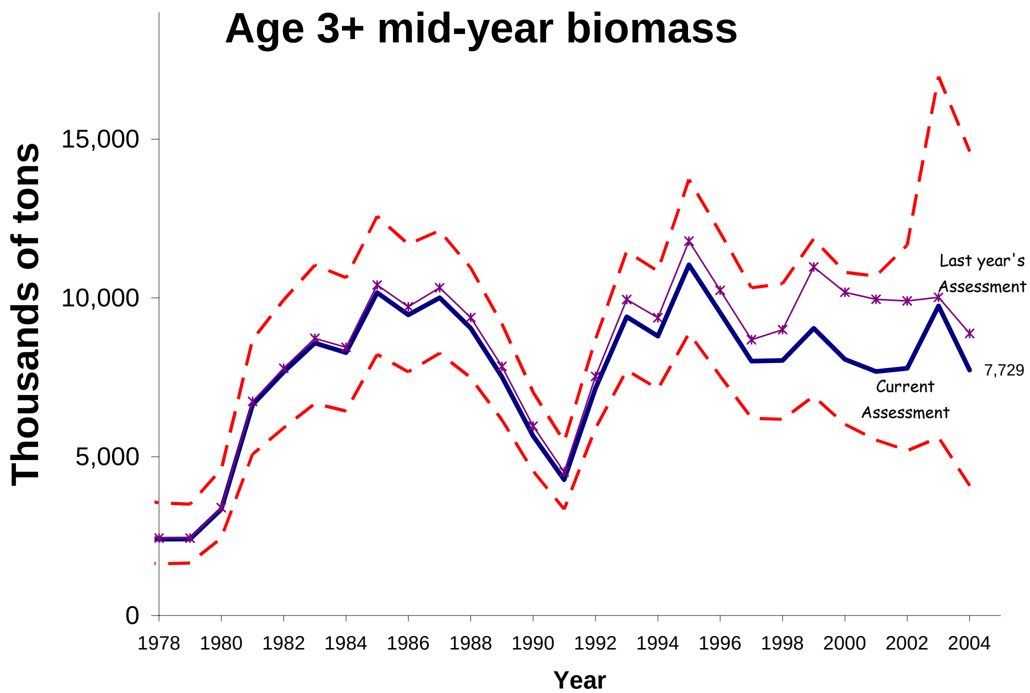


Figure 1.32. Estimated age 3+ EBS **mid-year** walleye pollock biomass under Model 1, 1978-2004. Approximate upper and lower 95% confidence limits are shown by dashed lines. Superimposed is the estimate of mid-year age 3+ biomass from last year's assessment

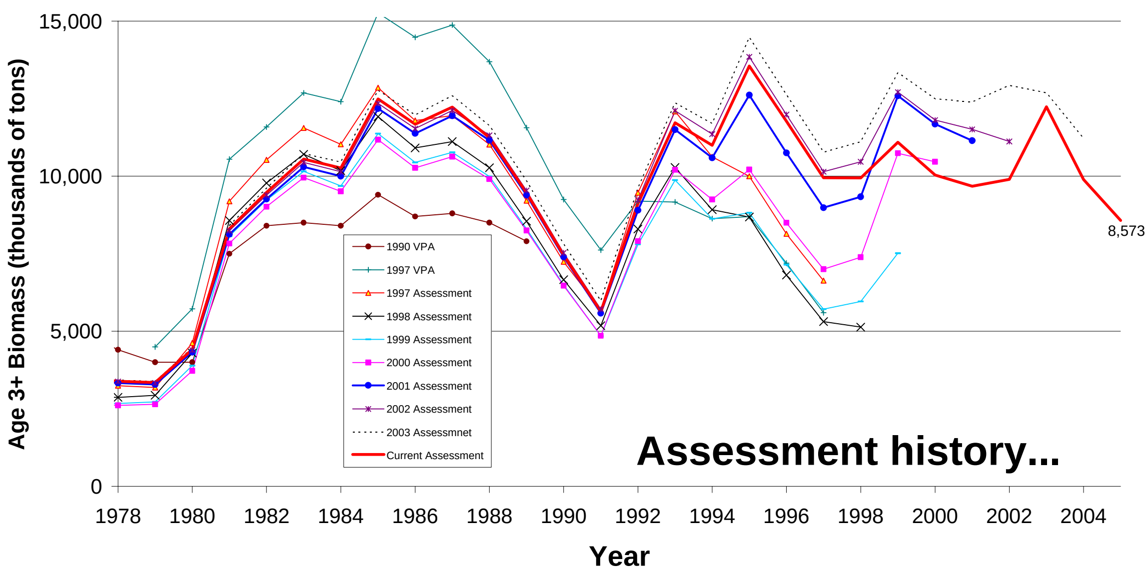


Figure 1.33. Comparison of the current assessment results with past assessments of **begin-year** EBS age-3+ pollock biomass, 1978-2005.

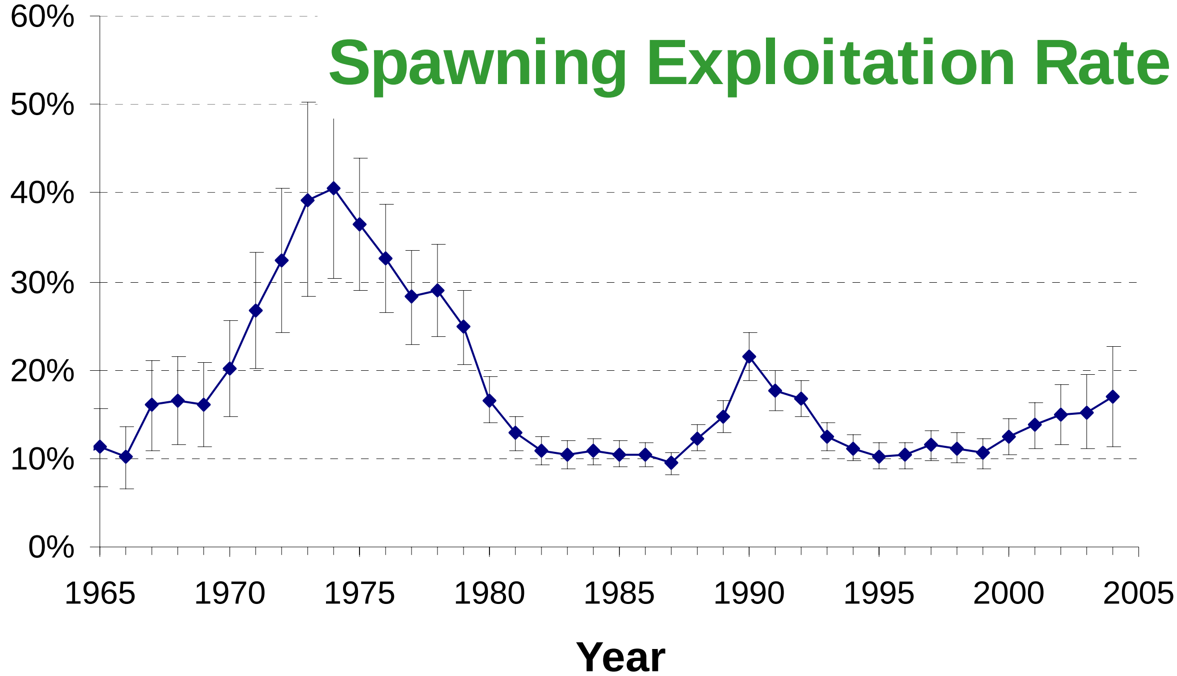


Figure 1.34. Estimated spawning exploitation rate (defined as the annual percent removals by fishing of spawning females) for EBS walleye pollock, Model 1. Error bars represent two standard deviations from the estimate.

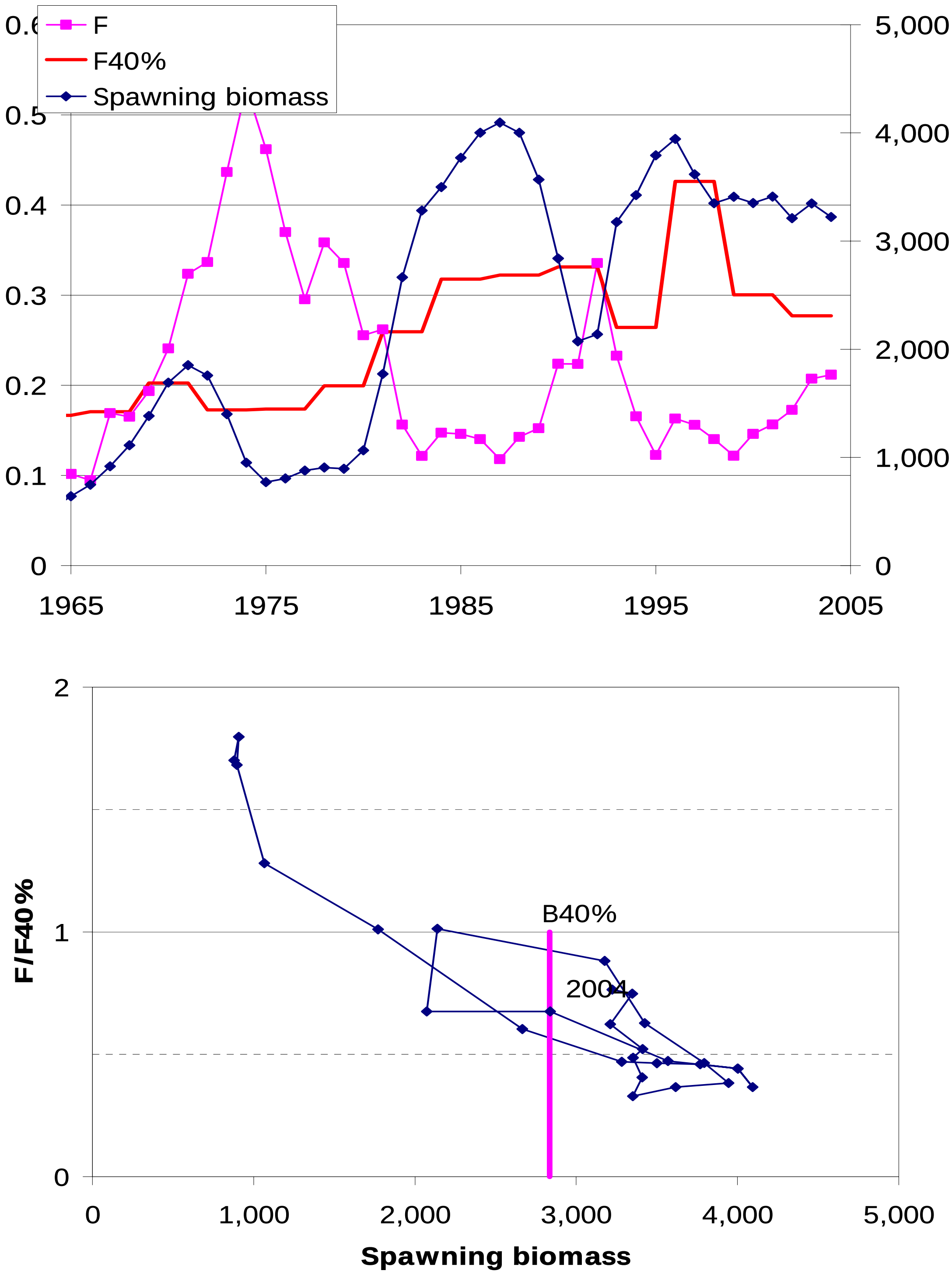


Figure 1.35. Spawning biomass relative to annually computed $F_{40\%}$ values and fishing mortality rates for EBS pollock, 1977-2004. Fishing mortality rates are based on the average over ages 1-15.

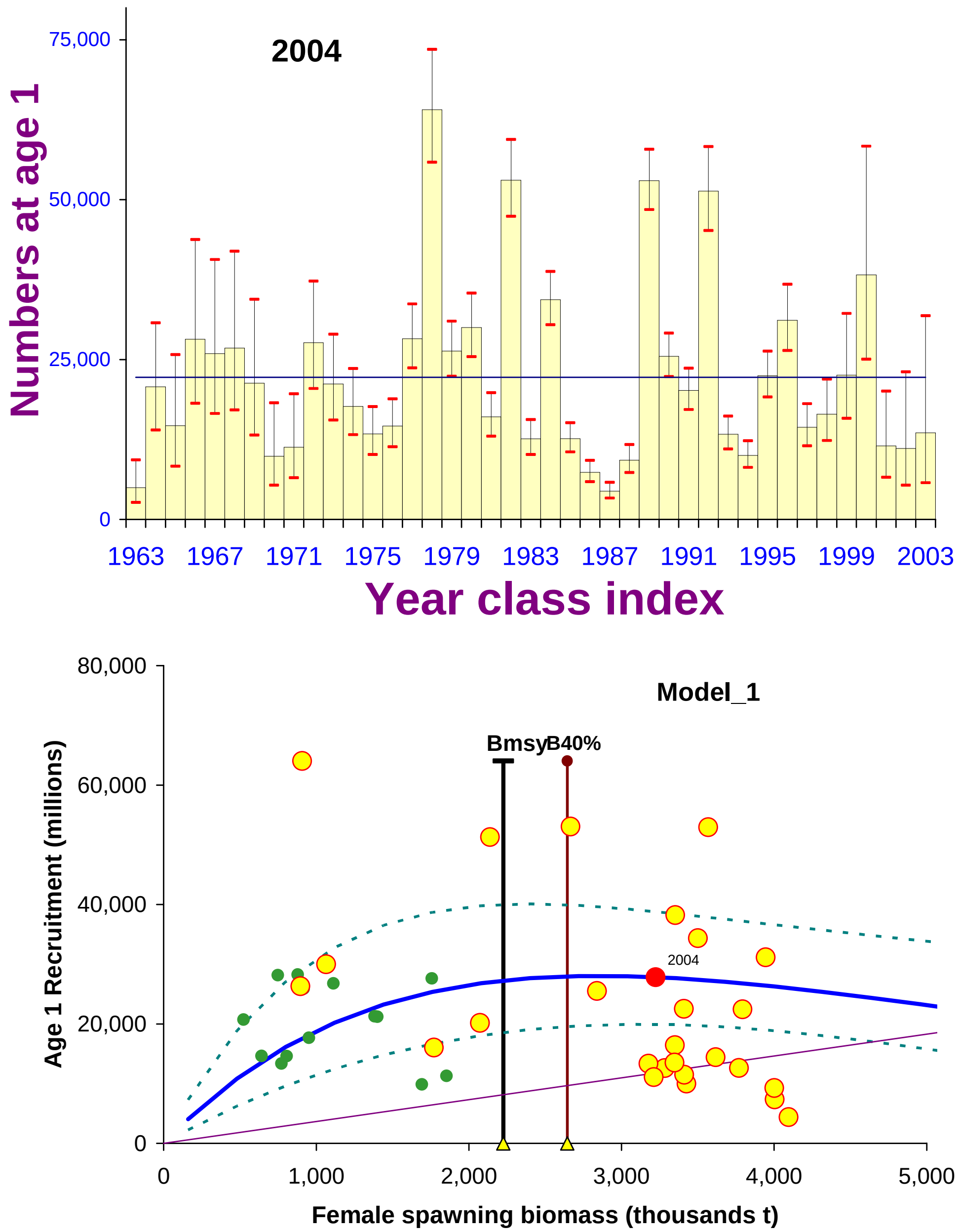
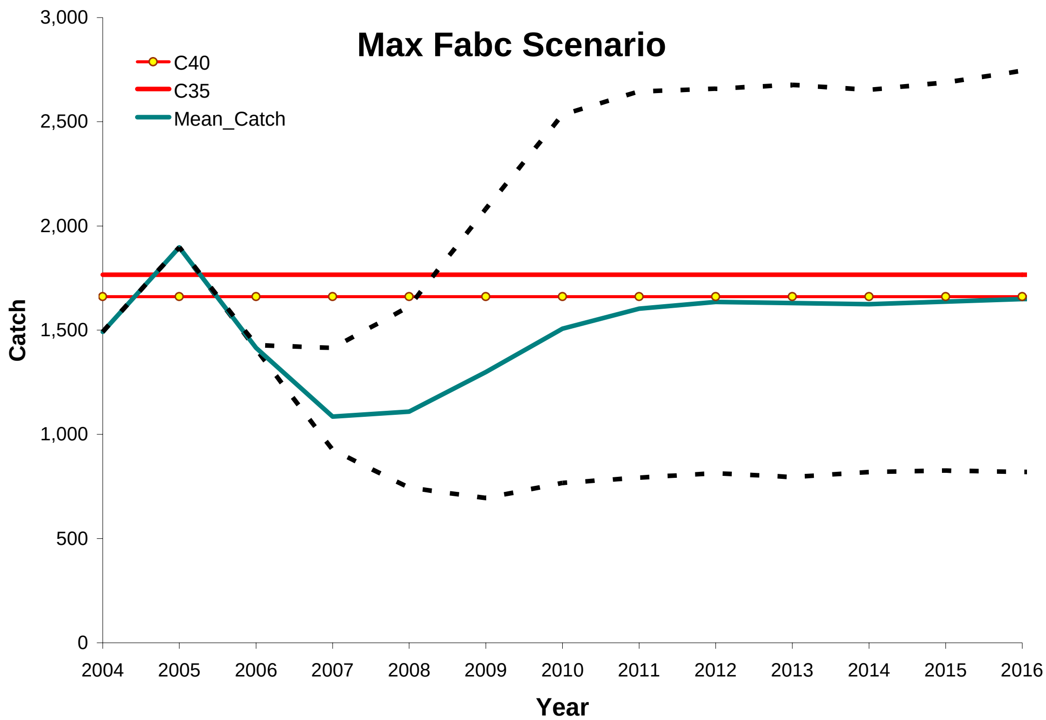


Figure 1.36. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS walleye pollock, Model 1. Solid line in upper panel represents the mean recruitment for all years since 1964. Vertical lines in lower panel indicate B_{msy} and $B_{40\%}$ level, curve represents fitted stock-recruitment relationship with diagonal representing the replacement lines with no fishing. Dashed lines represent lower and upper 95% confidence limits about the curve.



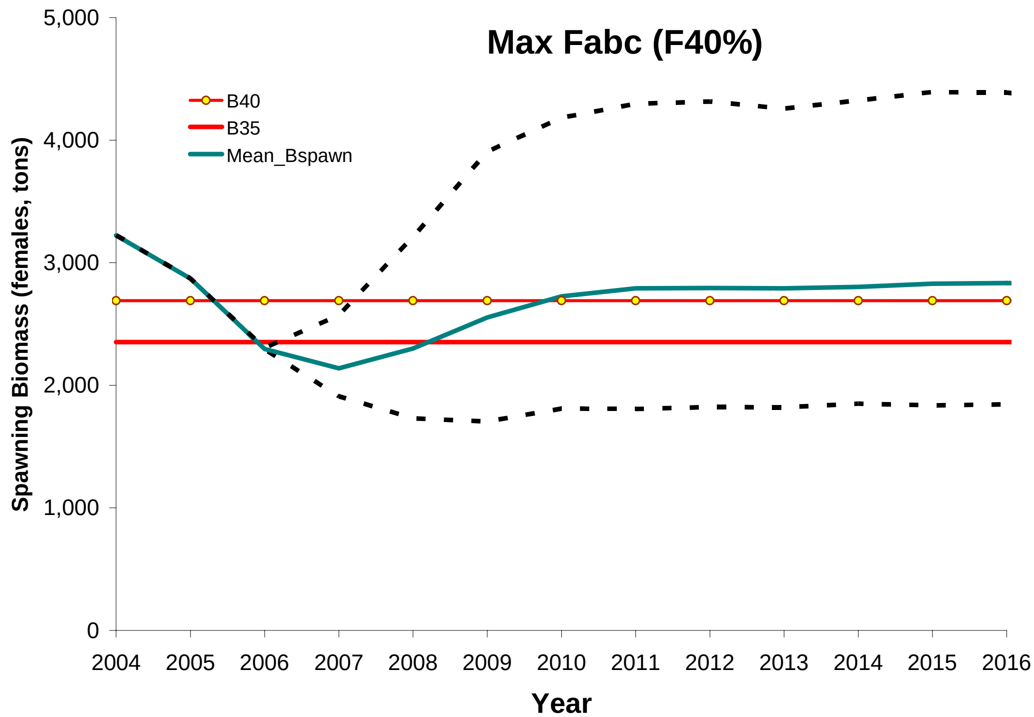


Figure 1.37. Projected EBS walleye pollock **yield** (top) and **Female spawning biomass** (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1. $B_{40\%}$ is computed from average recruitment from 1978-2004. Future harvest rates follow the guidelines specified under Scenario 1, max F_{ABC} assuming $F_{ABC} = F_{40\%}$.

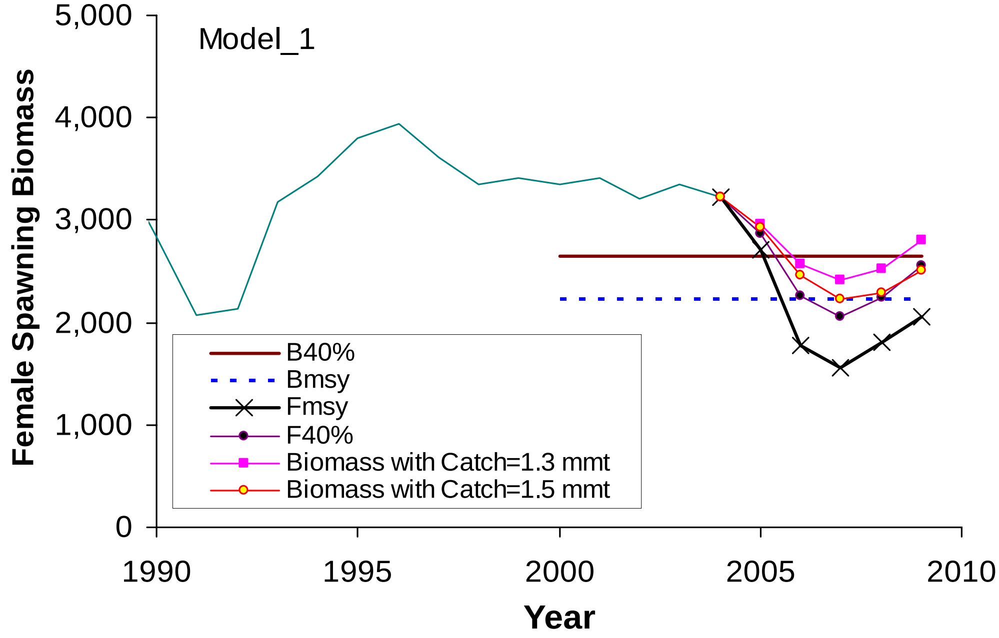


Figure 1.38. EBS walleye pollock female spawning biomass abundance trends, 1990-2009 as estimated by Model 1 under different 2005-2009 harvest levels. Note that the F_{msy} and $F_{40\%}$ catch levels are unadjusted arithmetic mean fishing mortality rates. Horizontal solid and dashed lines represent the B_{msy}, and $B_{40\%}$ levels, respectively.

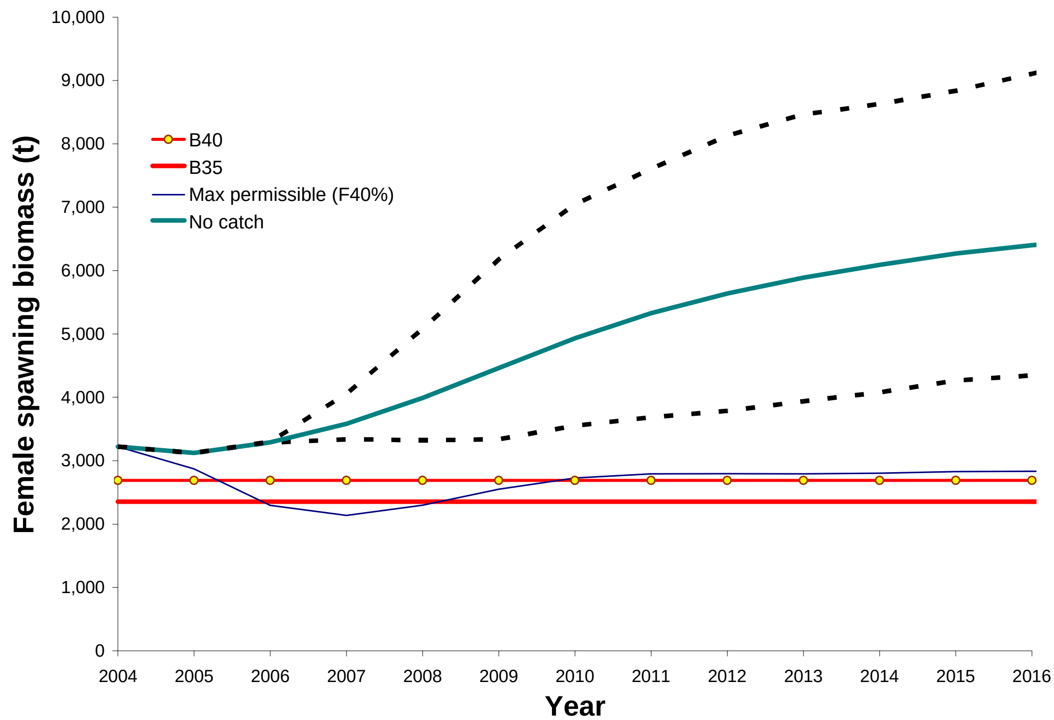
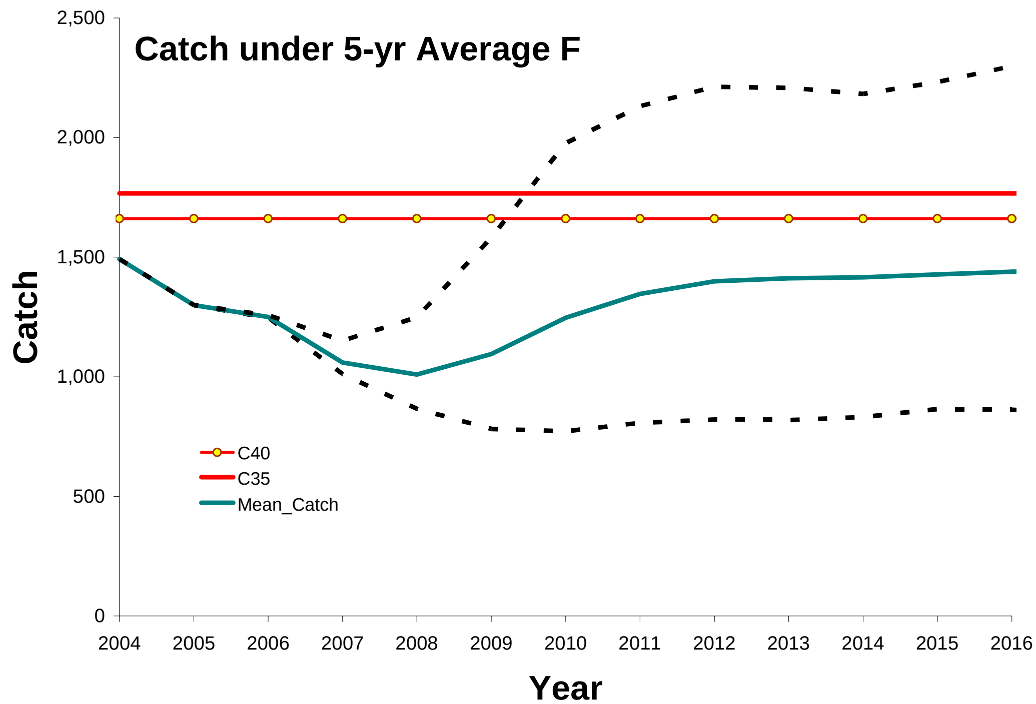


Figure 1.39. Projected EBS walleye pollock female spawning biomass under in the absence of fishing relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1. $B_{40\%}$ is computed from average recruitment from 1978-2004.



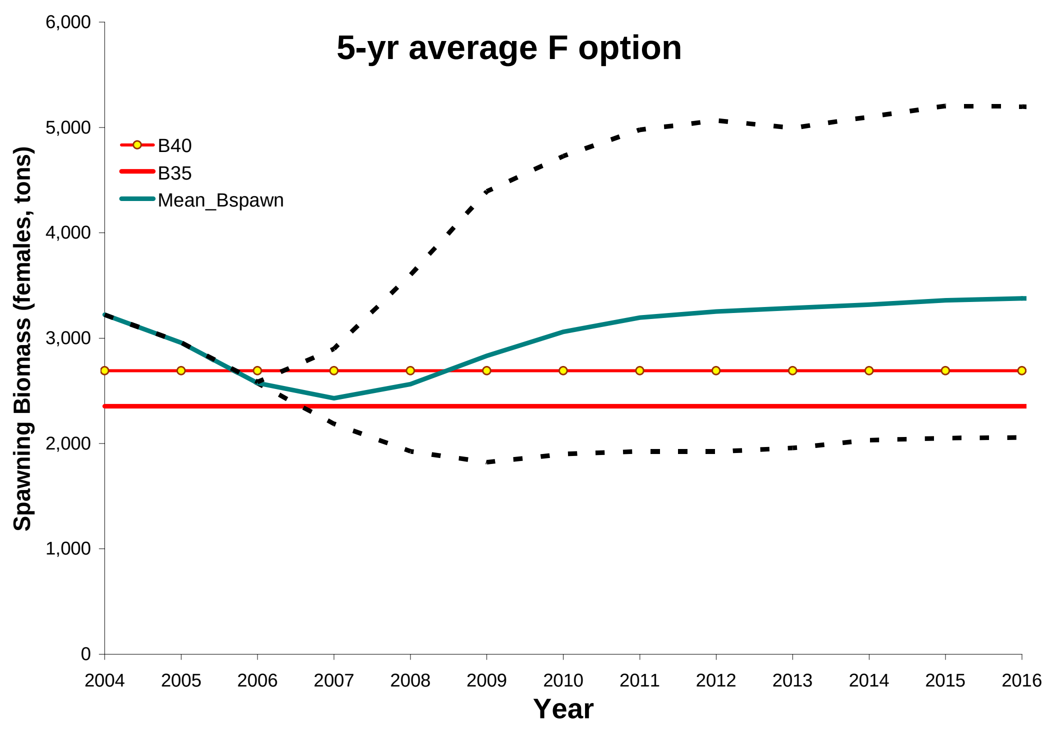


Figure 1.40. Projected EBS walleye pollock yield (top) and spawning biomass (bottom) under F equal to the mean value from 1999-2003 relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1.

Model details

Model structure

We used an explicit age-structured model with the standard catch equation as the operational population dynamics model (e.g., Fournier and Archibald 1982, Hilborn and Walters 1992, Schnute and Richards 1995). Catch in numbers at age in year t ($C_{a,t}$) and total catch biomass (Y_t) were

$$
\begin{aligned}
C_{t,a} &= \frac{F_{t,a}}{Z_{t,a}}\left(1-e^{-Z_{a,t}}\right)N_{t,a}, && 1 \le t \le T \quad 1 \le a \le A\\
N_{t+1,a+1} &= N_{t,a}e^{-Z_{t,a}} && 1 \le t \le T \quad 1 \le a < A\\
N_{t+1,A} &= N_{t,A-1}e^{-Z_{t,A-1}}+N_{t,A}e^{-Z_{t,A}} && 1 \le t \le T\\
Z_{t,a} &= F_{t,a} + M_{t,a}\\
C_{t\cdot} &= \sum_{a=1}^{A} C_{t,a}\\
p_{t,a} &= C_{t,a}/C_{t\cdot}\\
Y_t &= \sum_{a=1}^{A} w_a C_{t,a} \text{ , and}
\end{aligned}
$$

where

T	is the number of years,
A	is the number of age classes in the population,
$N_{t,a}$	is the number of fish age a in year t,
$C_{t,a}$	is the catch of age class a in year t,
$p_{t,a}$	is the proportion of the total catch in year t, that is in age class a,
$C_{t\cdot}$	is the total catch in year t,
w_a	is the mean body weight (kg) of fish in age class a,
$Y_{t\cdot}$	is the total yield biomass in year t,
$F_{t,a}$	is the instantaneous fishing mortality for age class a, in year t,
M_{ta}	is the instantaneous natural mortality in year t for age class a, and
Z_{ta}	is the instantaneous total mortality for age class a, in year t.

We reduced the freedom of the parameters listed above by restricting the variation in the fishing mortality rates ($F_{t,a}$) following Butterworth et al. (2003) by assuming that

$$
\begin{aligned}
F_{t,a} &= s_{t,a}\mu^f \exp\left(\varepsilon_t\right) && \varepsilon_t \sim N\left(0,\sigma_E^2\right)\\
s_{t+1,a} &= s_{t,a}\exp\left(\gamma_{t,a}\right), && \gamma_{t,a} \sim N\left(0,\sigma_s^2\right)
\end{aligned}
$$

where

$s_{t,a}$	is the selectivity for age class a in year t, and
μ^F	is the median fishing mortality rate over time.

If the selectivities ($s_{t,a}$) are constant over time then fishing mortality rate decomposes into an age component and a year component. This assumption creates what is known as a separable model. If selectivity in fact changes over time, then the separable model can mask important changes in fish abundance. In our analyses, we constrain the variance term (σ_s^2) to allow selectivity to change slowly over time–thus improving our ability to estimate the $\gamma_{t,a}$. Also, to provide regularity in the age component, we placed a curvature penalty on the selectivity coefficients using the squared second-differences. We selected a simple random walk as our time-series effect on these quantities. Prior assumptions about the relative variance quantities were made. For example, we assume that the variance of transient effects (e.g., σ_E^2) is large to fit the catch biomass precisely. Perhaps the largest difference between the model presented here and those used for other groundfish stocks is in how we model "selectivity" of both the fishery and survey gear types. The approach taken here assumes that large differences between a selectivity coefficient in a given year for a given age should not vary too much from adjacent years and ages (unless the data suggest otherwise, e.g., Lauth et al. 2004). The magnitude of these changes is determined by the prior variances as presented above.

The bottom-trawl survey selectivity was modified in 2002 to have an asymptotic form while retaining the properties desired for the characteristics of this gear. Namely, that the function allows for flexibility in selecting age 1 pollock. Additionally, time-varying shifts should be allowed. The selectivity for the BTS is therefore modeled as:

$$\begin{aligned} s_{t,a} &= \left[1 + e^{-\alpha_t(a-\beta_t)}\right]^{-1}, \; a > 1 \\ s_{t,a} &= \mu_s e^{\delta_t^\mu}, \qquad\qquad a = 1 \\ \alpha_t &= \bar{\alpha} e^{\delta_t^\alpha} \\ \beta_t &= \bar{\beta} e^{\delta_t^\beta} \end{aligned}$$

where the parameters of the selectivity function follow a random walk process as in Dorn et al. (2000):

$$\begin{aligned} \delta_t^\mu - \delta_{t+1}^\mu &\sim N\left(0, \sigma_{\delta^\mu}^2\right) \\ \delta_t^\alpha - \delta_{t+1}^\alpha &\sim N\left(0, \sigma_{\delta^\alpha}^2\right). \\ \delta_t^\beta - \delta_{t+1}^\beta &\sim N\left(0, \sigma_{\delta^\beta}^2\right) \end{aligned}$$

The parameters to be estimated in this part of the model are thus the $\bar{\alpha}, \bar{\beta}, \delta_t^\mu, \delta_t^\alpha, \text{and } \delta_t^\beta$ for t=1982, 1983,…2004. The variance terms for these parameters were specified to be 0.04.

In the SAM analyses, recruitment (R_t) represents numbers of age-1 individuals modeled as a stochastic function of spawning stock biomass. A further modification made in Ianelli et al. (1998) was to have an environmental component to account for the differential survival attributed to larval drift (e.g., Wespestad et al. 2000). (κ_t):

$$R_t = f\left(B_{t-1}\right) e^{\kappa_t + \tau_t} \;, \qquad \tau_t \sim \mathrm{N}\left(0, \sigma_R^2\right)$$

with mature spawning biomass during year t was defined as:

$$B_t = \sum_{a=1}^{15} w_a \phi_a N_{at}$$

and ϕ_a is the proportion of females that are mature at age a. The effect of larval drift on recruitment explained a relatively small part of the variance (Ianelli et al. 1998). This was confirmed in Mueter et al. (2004). The larval drift component of recruitment model was not included in this year's analysis.

Reparameterization of the stock-recruitment function

This year we implemented a reparameterized form for the stock-recruitment relationship as by Francis (1992). For the Beverton-Holt form we have:

$$R_t = f\left(B_{t-1}\right) = \frac{B_{t-1}e^{\varepsilon_t}}{\alpha + \beta B_{t-1}}$$

where

R_t is recruitment at age 1 in year *t*,

B_t is the biomass of mature spawning females in year *t*,

ε_t is the "recruitment anomaly" for year *t*,

α, β are stock-recruitment function parameters.

Values for the stock-recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (*h*). The "steepness" is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$
$$\beta = \frac{5h-1}{4hR_0}$$

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawner biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawning biomass (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of *h* = 0.9 implies that at 20% of the unfished spawning stock size will result in an expected value of 90% unfished recruitment level. Steepness of 0.7 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988). The same prior distribution for steepness based on a beta distribution as in Ianelli et al. (2001) and is shown in Fig. 1.41.

To have the critical value for the stock-recruitment function (steepness, *h*) on the same scale for the Ricker model, we begin with the parameterization of Kimura (1990):

$$R_t = f\left(B_{t-1}\right) = \frac{B_{t-1}e^{a\left(1-\frac{B_{t-1}}{\varphi_0 R_0}\right)}}{\varphi_0}.$$

It can be shown that the Ricker parameter *a* maps to steepness as:

$$h = \frac{e^a}{e^a + 4}$$

so that the prior used on *h* can be implemented in both the Ricker and Beverton-Holt stock-recruitment forms. Here the term φ_0 represents the equilibrium unfished spawning biomass per-recruit.

Parameter estimation

The objective function was simply the product of the negative log-likelihood function and prior distributions. To fit large numbers of parameters in nonlinear models it is useful to be able to estimate certain parameters in different stages. The ability to estimate stages is also important in using robust likelihood functions since it is often undesirable to use robust objective functions when models are far from a solution. Consequently, in the early stages of estimation we use the following log-likelihood function for the survey and fishery catch at age data (in numbers):

$$f = n \cdot \sum_{a,t} p_{at} \ln\left(\hat{p}_{at}\right) \ ,$$

$$p_{at} = \frac{O_{at}}{\sum_a O_{at}}, \qquad \hat{p}_{at} = \frac{\hat{C}_{at}}{\sum_a \hat{C}_{at}}$$

$$\hat{C} = C \cdot E_{ageing}$$

$$E_{ageing} = \begin{pmatrix} b_{1,1} & b_{1,2} & b_{1,3} & \cdots & b_{1,15} \\ b_{2,1} & b_{2,2} & & & \\ b_{3,1} & & \ddots & & \\ \vdots & & & \ddots & \\ b_{15,2} & & & & b_{15,15} \end{pmatrix} \ ,$$

where *A*, and *T*, represent the number of age classes and years, respectively, *n* is the sample size, and $O_{at}, \hat{C}_{at}$ represent the observed and predicted numbers at age in the catch. The elements $b_{i,j}$ represent ageing mis-classification proportions are based on independent agreement rates between otolith age readers. For Model 2 presented above, we implemented a revised ageing matrix. Sample size values were fixed at values shown in Table 1.10. Strictly speaking, the amount of data collected for this fishery indicates higher values might be warranted. However, it is well known that the standard multinomial sampling process is not robust to violations of assumptions (Fournier et al. 1990). Consequently, as the model fit approached a solution, we invoke a robust likelihood function which fit proportions at age as:

$$\prod_{a=1}^{A}\prod_{t=1}^{T} \frac{\left(\exp\left\{ -\frac{\left(p_{t,a} - \hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a} + 0.1/T\right)\tau^2} \right\} + 0.01 \right)}{\sqrt{2\pi\left(\eta_{t,a} + 0.1/T\right)}\tau}$$

Taking the logarithm we obtain the log-likelihood function for the age composition data:

$$-1/2 \sum_{a=1}^{A}\sum_{t=1}^{T} \log_e\left(2\pi\left(\eta_{t,a} + 0.1/T\right)\right) - \sum_{a=1}^{A} T \log_e(\tau)$$
$$+ \sum_{a=1}^{A}\sum_{t=1}^{T} \log_e\left[\exp\left\{ -\frac{\left(p_{t,a} - \hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a} + 0.1/T\right)\tau^2} \right\} + 0.01 \right]$$

where $\eta_{t,a} = \hat{p}_{t,a}\left(1-\hat{p}_{t,a}\right)$

and $\tau^2 = 1/n$

gives the variance for $p_{t,a}$

$$\left(\eta_{t,a} + 0.1/T\right)\tau^2 .$$

Completing the estimation in this fashion reduces the model sensitivity to data that would otherwise be considered "outliers."

Within the model, predicted survey abundance accounted for within-year mortality since surveys occur during the middle of the year. As in previous years, we assumed that removals by the survey were insignificant (i.e., the mortality of pollock caused by the survey was considered insignificant). Consequently, a set of analogous catchability and selectivity terms were estimated for fitting the survey observations as:

$$\hat{N}^s_{t,a} = e^{-0.5Z_{t,a}} N_{t,a} q^s_t s^s_{t,a}$$

where the superscript *s* indexes the type of survey (EIT or BTS). For these analyses we chose to keep survey catchabilities constant over time (though they are estimated separately for the EIT and bottom trawl surveys). The contribution to the negative log-likelihood function from the surveys is given by

$$\sum_{t^s}\left(\frac{\ln\left(A^s_{t\cdot}/\hat{N}^s_{t\cdot}\right)^2}{2\sigma^2_{t^s}}\right)$$

where $A^s_{t\cdot}$ is the total (numerical) abundance estimate with variance $\sigma^2_{t^s}$ from survey *s* in year *t*.

The contribution to the negative log-likelihood function for the observed total catches ($O_{t\cdot}$) by the fishery is given by

$$\lambda_c \sum_t \left(\log\left(O_{t\cdot}/\hat{C}_{t\cdot}\right)^2\right)$$

where λ_c represents prior assumptions about the accuracy of the observed catch data. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include

$\lambda_\varepsilon \sum_t \varepsilon_t{}^2 + \lambda_\gamma \sum_{ta} \gamma_{t,a}{}^2 + \lambda_\delta \sum_t \delta_t{}^2$ where the size of the λ's represent prior assumptions about the variances of these random variables. Most of these parameters are associated with year-to-year and age specific deviations in selectivity coefficients. For a presentation of this type of Bayesian approach to modeling errors-in-variables, the reader is referred to Schnute (1994). To easily estimate such a large number of parameters in such a non-linear model, automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries was used. This software provided the derivative calculations needed for finding the posterior mode via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gave simple and rapid access to these routines and provided the ability estimate the variance-covariance matrix for all dependent and independent parameters of interest. The approach we use to solve for F_{msy} and related quantities (e.g., B_{msy}, MSY) within a general integrated model context was shown in Ianelli et al. (2001).

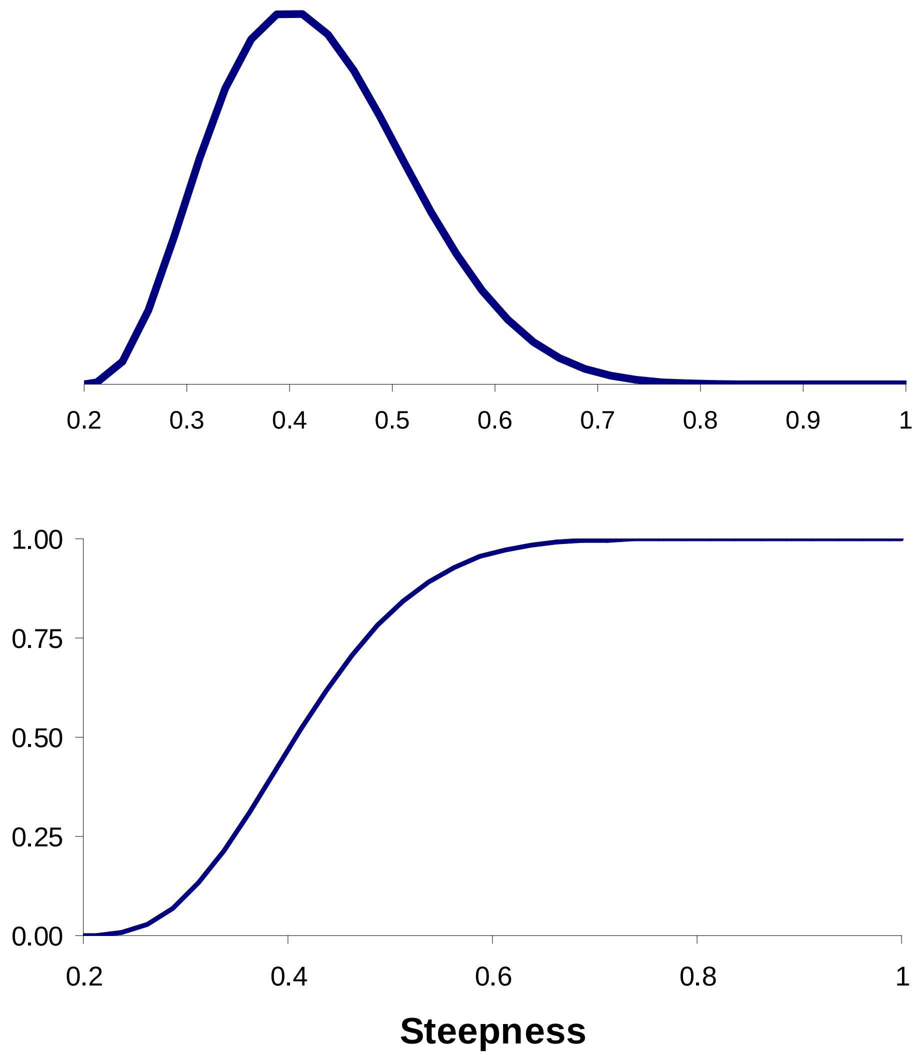


Figure 1.41. Cumulative prior probability distribution of steepness based on the beta distribution (α=4, β=10) assumed for the main model.

Aleutian Basin-Bogoslof Island Area

Since 1999 we have presented 2 alternative methods for computing ABC values for the Bogoslof region. They include:

1. The same method as in past years (with 2,000,000 ton estimate as a target stock size)
2. The Tier 5 method (F_{ABC} =0.75*M)

In 1999 we proposed a third method: a simplified age-structured model based on recent Bogoslof population trends. The Council SSC considered the age-structured model to be inappropriate since it covered only part of the stock and concurred with the Plan Team on placing Bogoslof pollock in Tier 5.

The information available for pollock in the Aleutian Basin and the Bogoslof Island area indicates that these fish belong to the same "stock". The pollock found in our surveys are generally older than age 5 and are considered distinct from eastern Bering Sea pollock. Data on the age structure of Bogoslof-Basin pollock show that a majority of pollock in the Basin originated from year classes that were also strong on the shelf, 1972, 1978, 1982, 1984, 1989, 1992, and 1996 (Fig. 1.42). There has been some indication that there are strong year classes appearing on the shelf that have not been coincidentally as strong (in a relative sense) in the Bogoslof region (Ianelli, et al. 2001). The conditions leading to strong year classes of pollock in the Basin appears to be density related and may be functionally related to abundance on the shelf. Additional information relating the total mortality of the 1992 cohort shows that the estimate is much higher than expected in the Bogoslof region compared to the EBS shelf (Fig. 1.43).

Differences in spawning time and fecundity have been documented between eastern Bering Sea pollock and Aleutian Basin pollock. Pollock harvested in the Bogoslof Island fishery (Area 518) have noticeably different age compositions than those taken on the eastern Bering Sea shelf (Wespestad and Traynor 1989). Pollock in the northern shelf have a similar size at age as Aleutian Basin pollock although a very different age composition. However, Aleutian Basin pollock may not be an independent stock. Very few pollock younger than 5 years old have ever been found in the Aleutian Basin including the Russian portion. Recruits to the basin are coming from another area, most likely the surrounding shelves either in the US or Russian EEZ.

ABC estimates for Bogoslof area

The National Marine Fisheries Service has conducted echo-integration-trawl (EIT) surveys for Aleutian Basin pollock spawning in the Bogoslof Island area annually since 1988, with three exceptions: a Bogoslof Island area EIT survey was not conducted in 1990 and 2004, and the 1999 Bogoslof Island area EIT survey was conducted by the Fisheries Agency of Japan. The annual Bogoslof Island area EIT survey results (Fig 1.44) show that the population declined between 1988 and 1994, and then has been stable with some increases (e.g., in 1995). The movement of pollock from the 1989 year class to the Bogoslof Island area was partly responsible for the 1995 increase (Fig. 1.45), but the abundance of all ages increased between 1994 and 1995. The decrease between 1995 and 1996 was followed by a continued decline in 1997. This suggests that the 1995 estimate may have been over-estimated, or that conditions in that year affected the apparent abundance of pollock. A small increase in estimated biomass in 1998 was followed by a continued decline in the 1999, 2000, and 2001 surveys. The current population levels on the eastern Bering Sea shelf, and the absence of extremely large year classes, suggests that pollock abundance will not increase significantly in the Bogoslof area in the coming years. The 1989 and 1996 year classes are the predominant year classes in the Bogoslof area. The 2003 Bogoslof Island EIT survey results have been published as an AFSC Processed Report (McKelvey and Williamson 2003). The summary Bogoslof Island area EIT survey biomass estimates, 1988-2003, are as follows:

Biomass (millions of t)

1988	1989	1990	1991	1992	1993	1994	1995	
2.4	2.1	-	1.3	0.9	0.6	0.49	1.1	
1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
0.68	0.39	0.49	0.48	0.30	0.23	0.23	0.20	No survey

Tier 5 computations use the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC (2003 survey biomass $\times M \times$ 0.75) of **29,700 t** at a biomass of 198,000 t (with $M = 0.2$). The OFL is **39,600 t**.

Given the survey estimate of exploitable biomass of 0.198 million t and M = 0.2 and based on the SSC discussions for further reductions in ABC based on considerations of a target stock size of 2 million tons, the F_{ABC} recommendation is computed as:

$$F_{abc} \leq F_{40\%} \bullet \left(\frac{B_{2003}}{B_{40\%}} - 0.05 \right) \Big/ (1 - 0.05) = 0.27 \bullet \left(\frac{198{,}403}{2{,}000{,}000} - 0.05 \right) \Big/ (1 - 0.05) = 0.014$$

Using a fishing mortality rate of 0.014 translates to an exploitation rate of 0.013 which when multiplied by 198,000 t, gives a **2004 ABC of 2,570 t for the Bogoslof region.**

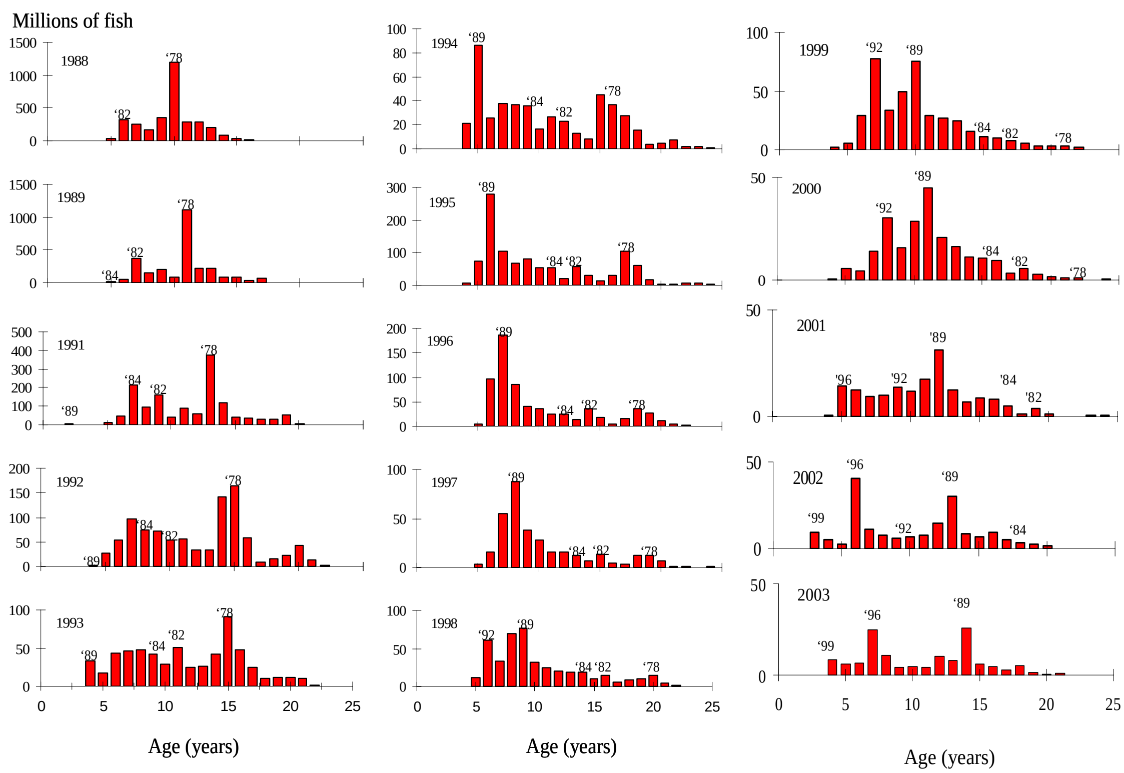


Figure 1.42. Numbers-at-age estimates (millions) obtained during echo integration-trawl surveys of walleye pollock near Bogoslof Island in winter 1988-2003. Major year classes are indicated. The United States conducted all but the 1999 survey (Japan). No survey was conducted in 1990. Note y-axis scales differ.

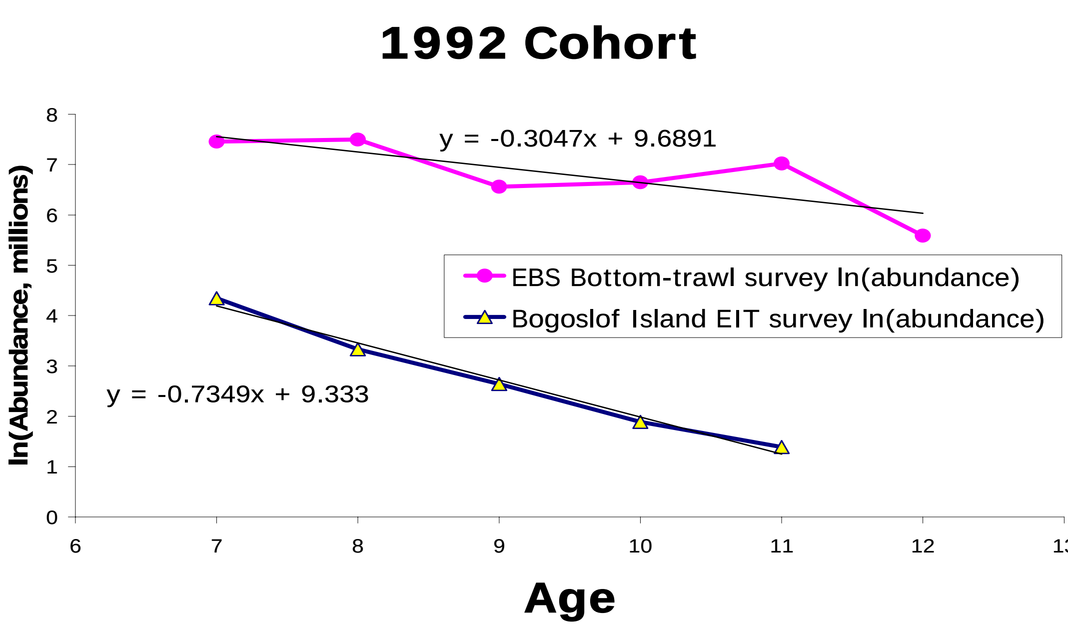


Figure 1.43. The 1992 pollock cohort abundances-at-age as observed from the EBS summer bottom trawl survey (top lines) and from the EIT survey in the Bogoslof region (lower lines).

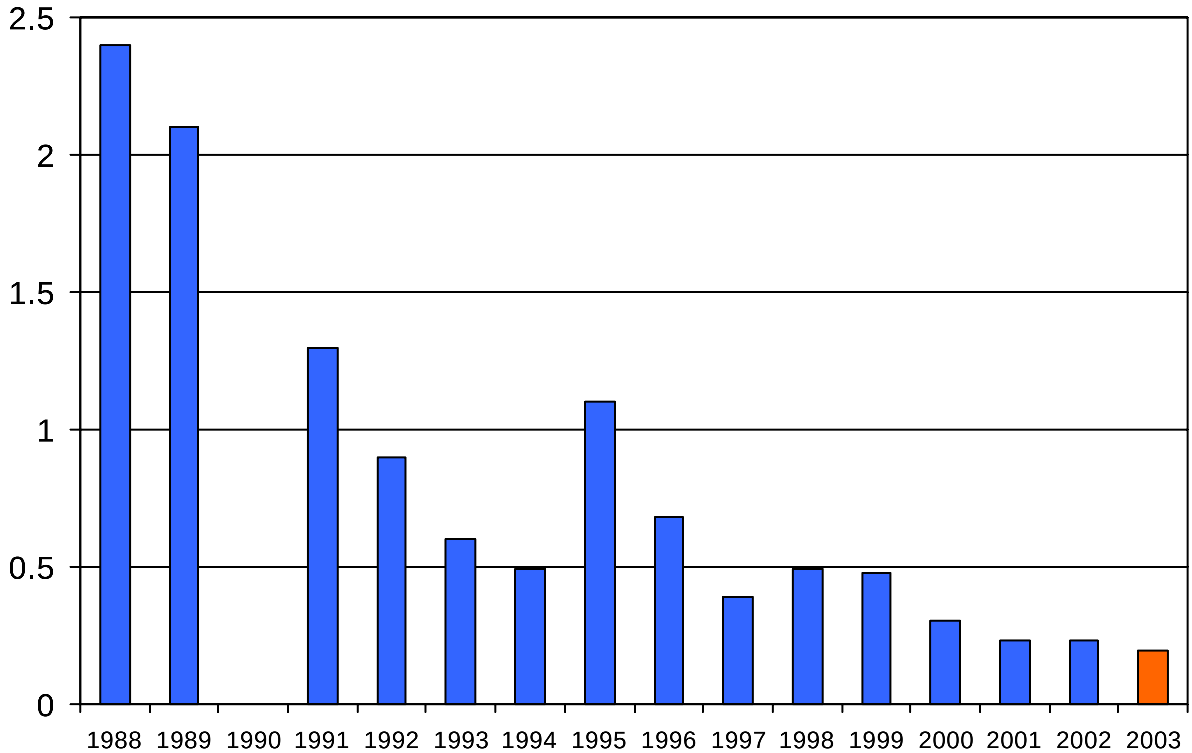


Figure 1.44. Pollock biomass estimates from the 1988-2003 Bogoslof Area EIT surveys in millions of tons. There were no surveys in 1990 and in 2004.

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